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Evaluation of Walleye Fry Stocking in Clear Lake, Iowa, by Alternate-Year Planting[1]

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ABSTRACT

Stocking of 5,000 to 9,500 walleye fry, *Stizostedion vitreum vitreum* (Mitchill), per acre in Clear Lake, Iowa, in the even-numbered years resulted in larger numbers of walleyes in those year classes than in the odd-numbered year classes (1949 to 1957) when no walleye fry were stocked. This conclusion was reached because (1) more walleye fingerlings were collected by seining beach areas in years of stocking than in years of no stocking; (2) age distribution of walleyes collected in experimental gill nets each year, 1947 to 1958, indicated that the even-numbered year classes were more abundant than the odd-numbered year classes; (3) catch of walleyes in even-numbered year classes, computed for an equal amount of experimental gill-netting, outnumbered those in year classes when there was no fry stocking by 3 to 1 during the first 6 years of the life of the fish; and (4) estimates of population by tagging and recovery techniques indicated that the 1950 year class was much greater than the 1949 year class.

INTRODUCTION

The stocking of fry in new habitats has often resulted in good survival and very rapid growth, but results from stocking fry in habitats already containing fish have often been very poor. Van Oosten (1937), Hile (1937), Carlander (1945), and Smith and Krefting (1954) reported that there was no correlation between the numbers of walleye fry, *Stizostedion vitreum vitreum* (Mitchill), stocked in large lakes and the subsequent abundance of adult walleyes. On the basis of these studies, walleye fry stocking was discontinued in the Great Lakes and in some other areas. Dymond (1957) stated (p. 391): "In summary it may be stated that there is no positive evidence that artificial propagation has ever been successful in significantly increasing the yield of a native species in the Great Lakes." Rose (1955) reported that the year classes of walleyes produced in Spirit Lake, Iowa, from 1944 through 1948, when no fry were stocked, were smaller than those produced from 1949 through 1954 when 1,800 to 3,000 fry per acre were stocked annually. Rose pointed out, however, that white bass *(Roccus chrysops)* were very abundant during the period when no walleye fry were stocked and were fairly low in abundance during the later period. White bass competition may have been as significant as the fry stocking in affecting the walleye year-class abundance.

Clear Lake in north-central Iowa is a shallow eutrophic lake of 3,600 acres with a mixed population of fish in which the walleye is the principal game species. For several

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years, the Iowa State Conservation Commission has operated a walleye hatchery on the lake, taking brood stock off the spawning areas, stripping the eggs and sperm, hatching the eggs in battery jars, and stocking most of the fry into the lake shortly after they hatch. In 1948 an alternate-year fry stocking schedule was established to provide data on the value of continued fry stocking. No eggs were taken nor were fry stocked in Clear Lake in 1949, 1951, 1953, 1955, and 1957, but over 5,000 fry were stocked per acre in each of the even-numbered years (Table 1).

TABLE 1.—*Number of fry stocked by the Clear Lake hatchery and subsequent capture of fingerlings by two methods*

Year	Number stocked per acre	Number captured per 500-foot seine haul	Rank	Number captured in short-seine hauls	Rank
1945	6,429	13.1	6	—	—
1946	5,270	39.6	13	—	—
1947	7,067	14.2	7	5	3
1948	9,566	21.5	11	91	9
1949	0	10.5	4	58	7
1950	8,850	14.5	8	212	11
1951	0	0.6	2	5	2
1952	5,449	23.3	12	23	5
1953	0	0	1	0	1
1954	7,000	20.0	10	142	10
1955	0	10.7	5	39	6
1956	7,070	19.0	9	277	12
1957	0	2.2	3	6	4
1958	7,340	51.0	14	74	8

RELATION BETWEEN FRY STOCKING AND NUMBER OF FINGERLINGS

Each year, State Conservation Department lake survey crews seined three to eight areas of Clear Lake with a 500-foot ¼-inch mesh seine to determine the abundance of young fish. The numbers of fingerling walleyes per seine haul were smaller in the 5 years of no hatchery operation than in other years (Table 1). The probability of this result happening by chance can be determined by a simple ranking test (Anderson and Bancroft, 1952). The sum of the ranks for the 5 years of no hatchery operation is $1+2+3+4+5=15$. The number of possible combinations of the numbers from 1 to 14 taken five at a time is $C(14,5)$, or 2,002. The probability of obtaining a sum as low as 15 by chance is 1/2002, or 0.005, since there is only one way of deriving the sum 15 from the numbers 1 to 14 taken five at a time.

The Iowa Cooperative Fishery Research Unit biologists have also collected data on the abundance of young fish in Clear Lake each summer since 1947. The young walleyes were collected by seining with a short minnow seine or bag seine (Table 1). The amount of effort differed considerably from year to year and the individual seine hauls could not be considered comparable, but the relative scarcity of walleye fingerlings in years of no hatchery operation still is apparent. The ranking test indicates that these results have a probability of occurring by chance 19 in 792 times, or 0.024.

It is possible, although not probable, that the stocked walleye fry behave differently than the naturally spawned fry and that the stocked fry can be caught as fingerlings along shore much more readily than the naturally spawned walleyes. In this case the relationship between fry stocking and fingerling numbers might mean little in providing catchable-sized walleyes.

RELATIONSHIP BETWEEN FRY STOCKING AND CATCHABLE-SIZED WALLEYES

An estimate of the relative abundance of walleyes in various year classes can be secured by examination of the scales collected over a series of years. Experimental gill nets of the same mesh sizes (25 feet each of 1.5, 2.0, 2.5, 3.0, and 4.0 inches stretch measure) were used to collect the walleyes for age determination each summer from 1948 through 1958. Although the assignment to year class may not be correct in all cases, the growth data and the persistence of year classes indicate that the age determinations are on the whole valid.

The percentages of walleyes in each age class in the annual gill-net catches indicate pronounced differences in the abundance of year classes (Table 2). For example, the 1950 and 1952 year classes are obviously relatively abundant. An index of the abundance of the various year classes can be derived as illustrated in Table 3. A ranking test indicates that a sum as low as $1+3+4+5+7=20$ would occur by chance only 19 of 462 times (0.04) taking five at a time from 11 ranks.

This index of abundance of year classes assumes that the population is numerically the same each year, an assumption which obviously is not true in view of the differences in year-class abundance. A year class preceding or following an abundant year class will

TABLE 2.—*Estimated percentages of walleyes of each year class captured each year in experimental gill nets at Clear Lake, Iowa*

Year class	Year of capture										
	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958
1957	—	—	—	—	—	—	—	—	—	—	5.7
1956	—	—	—	—	—	—	—	—	—	2.9	5.7
1955	—	—	—	—	—	—	—	—	4.4	2.3	2.9
1954	—	—	—	—	—	—	—	9.1	27.7	19.2	20.0
1953	—	—	—	—	—	—	1.4	4.6	10.2	12.2	25.7
1952	—	—	—	—	0.4	9.6	56.8	63.4	31.4	33.7	20.0
1951	—	—	—	—	9.4	6.9	8.8	6.9	11.7	11.0	2.9
1950	—	—	1.4	46.0	65.5	61.5	27.0	10.9	12.4	15.1	11.4
1949	—	—	4.6	27.2	13.4	15.6	3.4	0.6	1.5	1.7	—
1948	—	11.1	33.5	7.1	5.4	3.7	2.7	2.3	0.7	1.2	2.9
1947	15.1	52.5	37.0	12.9	1.9	2.3	—	0.6	—	—	—
1946	58.5	22.3	20.8	4.9	2.3	0.5	—	1.7	—	—	2.9
1945	15.7	10.0	1.4	0.9	1.1	—	—	—	—	0.6	—
1944	10.1	2.1	1.2	0.9	0.4	—	—	—	—	—	—
1943	0.6	0.9	—	—	0.2	—	—	—	—	—	—
1942	—	0.8	—	—	—	—	—	—	—	—	—
1941	—	0.3	—	—	—	—	—	—	—	—	—
Number sampled	153	659	346	224	519	218	148	175	137	172	35

show lower on a percentage basis than a year class of the same numerical abundance which happens to precede and follow year classes of average or low abundance.

Another approach involves the assumption that the catch in a given amount of effort is proportional to the abundance of the fish. If only the experimental gill nets set from June through August along the north shore of the lake, a fairly uniform habitat favorable to walleyes, are considered, there will probably be a fairly uniform unit of effort. The amount of netting along the north shore has been fairly low since 1953, and the mean catches show greater fluctuation than would be expected with larger samples (Table 4). The population certainly does not fluctuate as much from year to year as the catch. Data are available from other parts of the lake, but the amount of netting in various areas differed in different years, which would also affect the mean catch of walleyes, since they are not uniformly distributed over the lake. Since 1954, the same areas have been sampled each year in an attempt to increase the uniformity of sampling. The mean catch per net-day in the lake as a whole shows parallel but not as pronounced fluctuations as the data on the north shore alone. It is believed that in this case the errors due to uneven distribution of the sampling in various areas of the lake from year to year were less than sampling variation in the north-shore area with the smaller amount of netting.

TABLE 3.—*Derivation of index of abundance of walleyes in various year classes*[1]

Year class	Index of abundance of each age group						Weighted mean	Rank
	I	II	III	IV	V	VI		
1947	137	134	129	98	42	83	112	9
1948	121	119	70	64	85	99	91	6
1949	77	112	93	105	79	51	91	5*
1950	193	142	147	126	155	251	151	10
1951	113	66	78	74	160	239	94	7*
1952	114	137	148	132	228	299	154	11
1953	17	52	83	96	211	—	85	3*
1954	111	113	105	114	—	—	111	8
1955	75	28	38	—	—	—	40	1*
1956	54	59	—	—	—	—	58	2
1957	88	—	—	—	—	—	88	4*
Geometric mean percentage	7	19	16	14	8	3	—	—

[1]Since the data in Table 2 are percentages, geometric means were used to derive the indexes. For example, the index for the 1947 year class in 1948 was computed by dividing the log of 15.1 by the mean log of the percentages in age-class I each year's collection (or log 15.1 + log 11.1 . . . . + log 5.7, divided by 11) giving an index of 137. Since the variation of indexes was greater in age groups with smaller numbers, the indexes were weighted according to the mean percentage in each age group (last row) in completing the mean index for year class.

*Years when no fry were planted.

TABLE 4.—*Catch of walleye per 24-hour period in 125-foot experimental gill nets in Clear Lake, Iowa, June through August, 1947 to 1958*[1]

Year	North shore		Dominant age group[2]	Entire lake	
	Number of net-days	Mean catch per net-day		Number of net-days	Mean catch per net-day
1947	10.0	4.4	—	14.4	4.1
1948	45.2	4.4	II	45.2	4.45
1949	22.6	13.9	II	62.0	12.97
1950	20.7	18.0	III, II	20.7	18.02
1951	37.3	5.1	I, II	47.6	4.94
1952	28.1	14.8	II	55.3	11.12
1953	11.8	12.3	III	50.4	11.45
1954	8.0	11.6	II, IV	44.0	12.84
1955	6.0	27.4	III	17.4	11.97
1956	9.0	8.3	IV, II	29.0	5.16
1957	6.0	18.0	V, III	26.0	7.41
1958	6.0	5.4	IV	27.3	3.45

[1]In most cases nets were set for a full 24-hour period and fish removed at 2-hour intervals. Where nets were not set for full 24-hour period, the catch was adjusted (Carlander, 1953). Nylon nets frequently have been used in place of linen gill net since 1954. Because in paired nets linen caught 80 percent as many walleyes as nylon nets, the catches in the nylon nets were multiplied by 0.8.
[2]From Table 2.

The fluctuations are reasonably explained by the abundance of the age groups. It would appear from these data that age-group II walleyes are not as completely vulnerable to capture in the experimental gill nets as age-group III. Since Carlander (1945) reported that experimental gill nets caught walleyes with little size selectivity from 150 to 430 millimeters standard length (6.8 to 25.4 inches, total length), it was expected that age-group II fish would be fully vulnerable.

By multiplying the mean catch per net-day (Table 4) by the year-class composition for the same year (Table 2), the number of each year class caught per net-day (or 10 net-days, Table 5) can be determined. The ranking of the year classes differs slightly from the previous ranking, but the years when the hatchery was not operated are still rated low: 1, 2, 3, 5, and 7.

The average number of walleyes caught per 10 net-days during the first 6 years from year classes produced when the hatchery was operated is a little over three times as great as from year classes when no fry were stocked (Table 6). Some of this difference may be due to natural variations in year classes, but it would appear that the fry stocking is a significant factor in the abundance. If the big year class of 1950 is eliminated, the advantage of the fry-stocked year classes is still 116.7 to 42.9 fish taken in the first 6 years.

On the basis of tagging studies, Whitney (1958) estimated the numbers of walleyes in various year classes in 1953 (Table 7). The high abundance of the 1950 year class is evident. Since Whitney also estimated the annual mortality among walleyes to be 35 percent, the numbers of walleyes in the other year classes can be estimated at the time they

TABLE 5.—*Number of walleyes of each year class (1947-1957) and total catch taken per 10 net-days at Clear Lake, 1948-1958, with a ranking of year classes based upon the numbers*

Year class	Year of collection											Ranking of year class
	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	
1957	—	—	—	—	—	—	—	—	—	—	2.0	1*
1956	—	—	—	—	—	—	—	—	—	2.1	2.0	4
1955	—	—	—	—	—	—	—	—	2.3	1.7	1.0	2*
1954	—	—	—	—	—	—	—	10.9	14.3	14.2	6.9	6
1953	—	—	—	—	—	—	1.8	5.5	5.3	9.0	8.9	3*
1952	—	—	—	—	0.4	11.0	72.9	75.9	16.2	25.0	6.9	10
1951	—	—	—	—	10.5	7.9	11.3	8.3	6.0	8.2	1.0	5*
1950	—	—	2.5	22.7	72.8	70.4	34.7	13.0	6.4	11.2	3.9	11
1949	—	—	8.3	13.4	14.9	17.9	4.4	0.7	0.8	1.3	—	7*
1948	—	14.4	60.4	3.5	6.0	4.2	3.5	2.8	0.4	0.9	1.0	8
1947	6.7	68.1	66.7	6.4	2.1	2.6	—	0.7	—	—	—	9
Total number of walleyes per 10 net-days	44.5	129.7	180.2	49.4	111.2	114.5	128.4	119.7	51.6	74.1	34.5	—

*Years when no fry were planted.

TABLE 6.—*Average numbers of walleyes caught per 10 net-days during each year of life from year classes produced with and without fry stocking*

Age group	Mean catch in each year of life		Cumulative catch	
	No stocking	With stocking	No stocking	With stocking
I	5.0	11.8	5.0	11.8
II	7.1	48.4	12.1	60.2
III	8.1	46.1	20.2	106.3
IV	11.8	14.0	32.0	120.3
V	6.4	11.1	38.4	131.4
VI	4.5	4.9	42.9	136.3
VII	0.7	4.7	43.6	141.0
VIII	1.3	1.7	44.9	142.7
IX	0	0.4	44.9	143.1

were age III. The ratio of the numbers, as age III of the 1950 and 1949 year classes, 13,734 to 3,403 (or 4 to 1), is very similar to the ratio of the numbers taken in 10 net-days for the 8 years of life, 238.4 to 61.5, or 3.88 to 1 (Table 5). The correspondence between the two methods of estimating year classes is not as good with respect to the 1948 and 1947 year classes. The mortality rate may be higher than 35 percent or the population estimates may be less accurate. It is obvious that the annual mortality rate cannot be as high as 70 percent (Table 7).

DISCUSSION

Walleye fry stocking appears to have a significant effect on the walleye populations of Clear Lake, in sharp contrast to earlier studies on walleye fry stocking in Lake Huron and Lake Michigan (Hile, 1937), in Lake of the Woods (Carlander, 1945), and in the Red Lakes (Smith and Krefting, 1954). These other lakes are all much larger, and the rate of stocking was much less than in Clear Lake. In Saginaw Bay (Lake Huron) the number of fry stocked varied from 15 to 120 per acre, in Red Lake 40 to 430 walleye fry were stocked in various years, and in Lake of the Woods the number of fry stocked varied from about 400 to 1000 per acre. In Clear Lake, years of no stocking are contrasted with years in which 5 to 9.5 thousand fry were stocked per acre.

TABLE 7.—*Estimate of abundance of walleyes in various year classes in 1953 and when the year class was at age III, with assumed mortality rates of 35, 50, and 70 percent*

[Based on catches of 1953]

Age group	Year class	Estimate[1] in 1953	Age III With annual mortality of		
			35 percent	50 percent	70 percent
III	1950	13,734	13,734	13,734	13,734
IV	1949	2,212	3,403	4,424	7,374
V	1948	1,218	2,883	4,872	13,533
VI	1947	429	1,562	3,432	15,890
VII	1946	338	1,894	5,408	41,700

[1]Estimated from tag-and-recovery studies (Table 15 of Whitney, 1958).

In the other lakes many of the walleyes spawn in streams tributary to the lakes, whereas all spawning is in the lake itself at Clear Lake. The spawning areas are gravel and rocky shallows, mostly located along the south shore of the lake. Bullheads and yellow bass have been noted to be abundant on the walleye spawning beds and have been found to feed rather extensively on walleye eggs and fry. It is highly probable that they take a high percentage of the walleye fry as they emerge from the gravel. The bullheads and yellow bass, on the other hand, are not concentrated in the areas where the walleye fry are stocked and therefore the stocked fry may show a higher survival. It would be very interesting if data from an alternate-year stocking program were available from the 1920's or 1930's before the yellow bass became established in Clear Lake and when bullheads were less abundant.

TABLE 8.—*Relationship between number of fry stocked per acre and the relative abundance of the year classes formed in years of planting*

[Rankings based on various types of analysis]

Year	Number of fry	Ranking of year class			
		500-foot seine[1]	Short seine[1]	Scale readings[2]	Catch in gill nets[3]
1948	9,566	11	9	5	8
1950	8,850	8	11	11	11
1947	7,067	7	3	8	9
1954	7,000	10	10	9	6
1952	5,449	12	5	10	10
1956	7,070	9	12	2	4
1958	7,340	14	8	—	—

[1]Table 1.
[2]Table 3.
[3]Table 5.

There is a possibility that the alternation in abundance of year classes is not the result of fry stocking but is due to natural causes. The 1950 year class may have been unusually successful because weather and water conditions during the spawning and early growth periods were favorable. The abundance of yearling fish might then reduce the survival of the 1951 year class. In this way an alternate-year cycle of abundance might be estab-

lished. To test whether the observed population changes are due to the stocking, a change in the pattern of fry stocking is being made. Fry were stocked in 1958, 1959, and 1960 and will be stocked in 1962 and 1963, but not in 1961 or 1964. If there are then 2 good years alternating with one poor year class, it will indicate that the fry stocking is the controlling factor.

Since 1955 water levels have dropped in Clear Lake as the result of drought, and in the autumns of 1958 and 1959, with levels over 3 feet below the outlet, the area of the lake was significantly reduced. These water-level changes probably are the reason for the general decline in gill-net catches since 1955 (Table 4) and the apparent low abundance of the year classes since 1955 which cannot be evaluated fully until a few more years' data are available.

Since the number of stocked fry varied from 5,449 to 9,566 per acre, it might be anticipated that the size of the year class would be related to the number of fry stocked (Table 8). Apparently stocking 9,500 fry gives no detectable advantage over stocking 5,000 fry per acre.

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Growth of Brown Trout in Selected Pennsylvania Streams[1]

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ABSTRACT

Samples of age-groups O and I fish from wild populations of brown trout *(Salmo trutta* Linnaeus) indicated a similarity in the periodicity of growth in three streams in Pennsylvania. Growth in length of trout of both age groups followed a similar pattern in the three streams, with the most rapid growth occurring in the spring and very little growth occurring in the winter months. Estimates of the mean total length at the end of two complete growing seasons were 7.0, 7.8, and 8.5 inches, respectively, for the three streams. Values of the exponent *b* of the customary length-weight formula were similar among the three populations, varying from 2.94 to 3.01. Annual variations in condition of the trout were also similar in the three streams. An increase in condition in the spring coincided with an increase in growth rate; a drop in condition in fall and winter was accompanied by slower growth. The trout population in Spruce Creek had the highest average condition throughout the year. This population also had a significantly greater mean length than the other two at the end of the 2-year period. The specific growth rate in weight of age-group O trout in Spruce Creek declined from a high of 5.6 percent of their body weight per day in early June to negative values in November and December. During the second summer of life the specific growth rate increased to a high of 3.1 percent per day in April and subsequently decreased to a very low value in fall and winter.

INTRODUCTION

The growth of fishes has importance to the ecologist as a biological phenomenon associated with productivity, and also to the practical fishery manager who is concerned with maintaining productivity at the highest possible level. Most of the studies of growth in fishes have been restricted to a determination of the annual increments in length of the different age groups sampled from the population. Among the many studies of the brown trout *(Salmo trutta* Linnaeus) which include such data are those by Lee (1912), Dahl (1918), Went and Frost (1942), and Schuck (1945). Until quite recently, however, the lack of efficient collecting equipment has precluded the possibility of examining in detail the variation in growth in a wild population within a particular year as was attempted by Allen (1951).

Brown (1946a, b, c, 1951) studied various aspects of the growth of individual brown trout spawned from domesticated hatchery strains and reared under controlled laboratory conditions. While these studies yielded much useful information concerning the effects of environmental factors on growth, they cannot be used indiscriminately to explain the performance and behavior of natural populations. For this reason, it was considered desirable to determine the seasonal variation in growth of self-sustaining populations of brown trout in three streams in Pennsylvania. Studies were conducted over a period of 1 year and were restricted for many aspects of growth to the two youngest age groups present. Trout older than 2 years are not abundant in these streams due to natural mortality and angling mortality.

DESCRIPTION OF THE STUDY AREAS

Two of the sites chosen for study were located on small headwater streams tributary to the Susquehanna River: Spruce Creek draining a limestone-rich valley in the Ridge and Valley Province of the Appalachian Mountains, and Kettle Creek draining a hilly portion of the Allegheny Plateau. The other stream, East Branch of the Tionesta Creek, is a tributary to the Allegheny River in the Mississippi drainage. All three streams are subjected to severe flooding. Although no measurements of stream flow were made, the streams appeared to have similar volumes of flow during the period of the study. The total alkalinity of the water, expressed as calcium carbonate, varied from 130-135 p.p.m. in Spruce Creek, 10-15 p.p.m. in Kettle Creek, and 15-20 p.p.m. in Tionesta Creek. Although no detailed study of the fish populations of

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the three streams was made, periodic collections indicated a difference in the numbers of species present (Table 1). In Spruce Creek the brown trout and the slimy sculpin (*Cottus cognatus)* made up the majority of the population. In both Kettle Creek and Tionesta Creek the brown trout was associated with many other species.

SAMPLING METHODS

For reasons stated below, no attempt was made to determine the total number of fish present in the stream section on each sampling date, but electrofishing was continued in most cases until an adequate number of fish of age-groups 0 and I were taken. Several fish-growth studies summarized by Carlander (1956) showed that a sample size of about 30 fish was usually sufficient to indicate 5 percent differences in the mean lengths as significant at the 95 percent level of probability. In this study such a sample size proved to be adequate to compare differences in mean lengths between collections at the same level. It was not always possible, however, to catch adequate samples of fish in Kettle Creek with electrofishing gear due to low conductivity and occasional high water.

The direct-current electrofishing device employed has been shown to be more efficient in taking large fish, but also is capable of sampling up to 30 percent of fish as small as 2 inches in length (Schuck, 1945). The size of the stream, turbidity of the water, electrical conductivity of the water and stream bottom, stream velocity, and alertness of the operators all influence the proportion of fish that can be captured from a given population. Because electrofishing gear catches the larger individuals of the same year class with greater efficiency, mean lengths of the samples are biased and somewhat higher than the actual population. Since this slight but uniform bias would not create any substantial error in the comparisons between seasons or the different streams, correction for it was not considered necessary.

Sampling was begun in Spruce Creek on March 7, 1958. During the time of expected fast growth (April 11 to August 2) samples were taken at 2-week intervals, and during the remainder of the period (August 1958 to the end of February 1959), once per month. It would have been desirable to begin sampling on all three streams in March 1958, prior to the time when the fry and yearling fish began active growth; however, the brown trout populations in Kettle Creek and Tionesta Creek were not sufficiently known at that time to permit choosing study areas on these streams. Also, during the latter part of the study, high water conditions and icy roads made collections in these streams impractical. Complete seasonal data from Kettle Creek and Tionesta Creek are therefore not available, but sufficient collections were made to permit some comparison of growth between these two streams and Spruce Creek.

TABLE 1.—*List of fishes collected in the three study areas during this investigation, together with their relative abundance, as estimated by sampling with electrofishing gear*

[S—Spruce Creek; K—Kettle Creek; T—Tionesta Creek; A—abundant; C—common; P—present.]

Scientific name	Locality and abundance		
	S	K	T
Salmonidae			
Salmo trutta	A	C	C
Salvelinus fontinalis	P	C	C
Catostomidae			
Hypentelium nigricans	—	P	C
Catostomus commersoni	P	C	C
Cyprinidae			
Hybopsis micropogon	—	P	—
Rhinichthys atratulus	P	A	A
Rhinichthys cataractae	P	C	—
Clinostomus elongatus	—	—	C
Semotilus atromaculatus	P	C	C
Semotilus margarita	—	P	P
Exoglossum maxillingua	—	C	—
Notropis cornutus	—	C	P
Pimephales notatus	—	—	P
Campostoma anomalum	—	C	—
Ictaluridae			
Noturus insignis	—	C	—
Centrarchidae			
Micropterus dolomieui	—	P	—
Lepomis gibbosus	—	P	—
Percidae			
Percina maculata	—	—	P
Etheostoma nigrum	—	—	P
Etheostoma olmstedi	—	C	—
Etheostoma blennioides	—	—	P
Cottidae			
Cottus bairdi	—	—	A
Cottus cognatus	A	C	—

GROWTH IN LENGTH

The seasonal growth pattern did not vary markedly in any of the trout populations studied. About half of the yearly growth occurred in the 2-month period from the middle of April to the middle of June, while there was almost no growth during the months of December, January, February, and March (Figure 1). The annual growth of brown

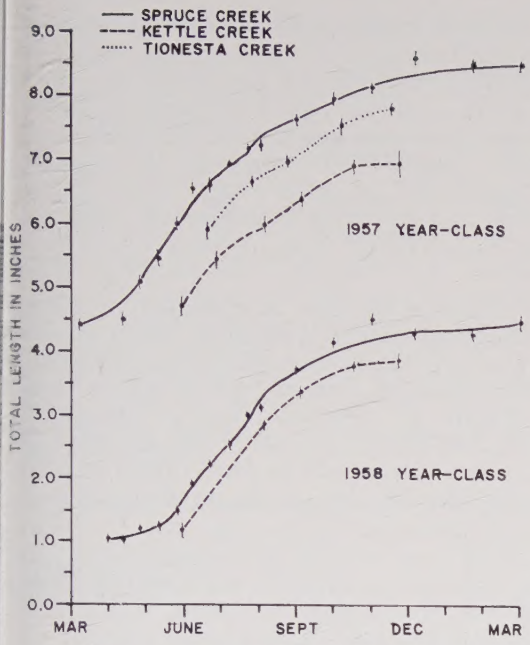

FIGURE 1.—Growth in length of brown trout during first 2 years of life—1958-59. Growth lines for Spruce Creek fitted by moving average of threes; vertical lines indicate one standard error plus or minus about the mean.

trout in the three streams in Pennsylvania is near the middle of the range of values reported for this species (Frost, 1945; Allen, 1951), and somewhat faster than brown trout from Crystal Creek, New York (Schuck, 1945).

In Spruce Creek there seems to be some difference between age groups in the time of year when growth increases rapidly. Although the data seem to indicate that the yearlings begin growth before the young-of-the-year do, this difference probably does not occur because there is an extended recruitment of swim-up fry. The first young-of-the-year were collected on March 28, 1958. At this time some fish had already reached a length of 1.1 inches. Since brown trout fry average about 0.9 inch long when they swim up and begin feeding (Brown, 1946a, 1951), it is assumed that the first fry emerged at least as early as March 21. On May 9, however, some fry were as small as 0.9 inch. These fish must have emerged as late as early May. The result of this extended recruitment is to delay the apparent growth period of young-of-the-year trout about 3 weeks. It is possible, therefore, that many young fish began to grow somewhat earlier in the spring than did the yearlings.

In comparing the growth of trout in the three streams it is apparent that the brown trout in Spruce Creek gained an advantage in growth over those in both of the other streams early in the first growing season (Figure 1). The exact cause of this superior growth of Spruce Creek fish is incompletely known; but it is partially attributed to a greater abundance of food, such as reported by Frost (1945) for the brown trout in the River Liffey, Ireland, or to a lesser amount of competition from other fishes (Table 1).

LENGTH-WEIGHT RELATIONSHIP

The length-weight relationship of fishes has interested fishery biologists for some time because it affords an opportunity to study changes in body form as the fish grows. It also has value in predicting the expected weight of a fish when only the length is known. The length-weight relationship of brown trout in the three streams investigated was determined from the combined data from all of the collections taken at different times of the year, and depicts the average relationship insofar as the collections are distributed throughout the entire year. This method is believed to be superior to the practice of computing the length-weight relationship based on one large sample taken on a particular date because there is a large variation in weight that occurs seasonally in many species of fishes.

The length-weight relationship was computed from the formula given by Ricker (1958):

$$w = al^b$$

where w = weight in grams, l = total length in inches, and a and b are constants.

The similarity in length-weight relationships of the brown trout populations in the three streams studied is apparent from a comparison of the expected weight at different sizes computed from the length-weight curves of the different streams (Table 2). The values of the exponent, b, in the length-weight equations of the trout in the three streams do not differ greatly from 3.0. Brown (1957) reported a value of 3.0 for the Lake Windermere brown trout, and Schuck (1942) reported a value of 3.003 for wild brown trout in Crystal Creek, New York.

TABLE 2.—*Length-weight relationship of brown trout from the three study areas with a comparison of expected weights at specified total lengths*

[w = weight in grams; l = total length in inches.]

Stream	Size range	Number of fish	Length-weight relationship	Expected weight	
				5 inches	10 inches
Spruce Creek	4.5–11.9	1,139	$w = 1.76\ l^{2.94}$	20.0	153.4
Tionesta Creek	5.0–10.9	191	$w = 1.69\ l^{2.95}$	19.4	150.1
Kettle Creek	4.5–10.9	136	$w = 1.48\ l^{3.01}$	18.8	151.0

SEASONAL CHANGE IN CONDITION

For the brown trout the well-known cube law appears to describe the length-weight relationship quite accurately, since values of b are very close to 3.0. Historically this observation on other species of fish led to the development of a condition factor based on the formula:

$$w = Cl^3$$

Several such factors have been described utilizing different units of measurements and employing different methods for measuring the length of the fish. Since no one of these has any decided advantage over another, the index described by Cooper and Benson (1951) was used because of the practice of weighing the fish in grams and measuring the total lengths of the fish in inches. The weight is arbitrarily multiplied by a factor of 10 to give the condition factor the magnitude of one.

Seasonal changes in condition of brown trout were similar in the three streams studied with a peak condition being reached during the month of June, at least in Spruce Creek (Figure 2). The low value of about 1.50 reached during fall and winter, and the high value of about 1.75 in June (Table 3) were very close to the maximum and minimum

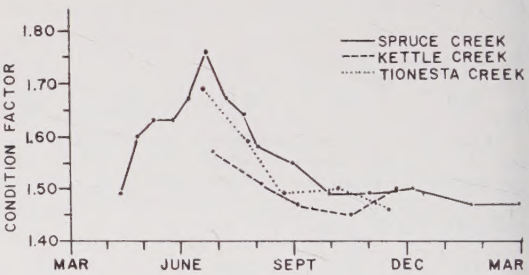

FIGURE 2.—Change in condition of yearling brown trout in three Pennsylvania streams during a calendar year—1958-59.

TABLE 3.—*Seasonal change in condition of yearling brown trout in three Pennsylvania streams*

Stream and date	Number of individuals	Condition factor		
		Mean	Standard error of mean	Range
Spruce Creek				
4-11-58	39	1.49	0.015	1.32–1.76
4-25-58	36	1.60	0.020	1.27–1.90
5-9-58	28	1.63	0.017	1.43–1.76
5-24-58	53	1.63	0.019	1.28–1.92
6-7-58	51	1.67	0.015	1.46–1.98
6-21-58	59	1.76	0.019	1.54–2.19
7-7-58	58	1.67	0.011	1.46–1.88
7-21-58	61	1.64	0.011	1.45–1.83
8-2-58	56	1.58	0.011	1.39–1.72
8-29-58	70	1.55	0.011	1.39–1.85
9-28-58	65	1.49	0.011	1.33–1.73
11-1-58	54	1.49	0.013	1.31–1.76
12-4-58	46	1.50	0.017	1.31–1.86
1-20-59	46	1.47	0.012	1.26–1.66
2-28-59	60	1.47	0.011	1.31–1.73
Kettle Creek				
6-26-58	23	1.57	0.015	1.44–1.72
8-4-58	13	1.51	0.021	1.40–1.64
9-3-58	37	1.47	0.016	1.28–1.66
10-15-58	51	1.45	0.013	1.27–1.72
11-22-58	12	1.50	0.032	1.30–1.77
Tionesta Creek				
6-18-58	10	1.69	0.028	1.59–1.80
7-23-58	38	1.59	0.013	1.44–1.80
8-22-58	41	1.49	0.018	1.20–1.69
10-5-58	48	1.50	0.013	1.32–1.80
11-15-58	47	1.46	0.012	1.28–1.63

values of the brown trout condition reported by Cooper and Benson (1951) in the Pigeon River, Michigan, and by Ellis and Gowing (1957) in Houghton Creek, Michigan. Differences between trout of the three streams were not large but appeared to be consistent, with Spruce Creek fish maintaining the highest condition throughout most of the year and trout from Tionesta Creek usually being in better condition than the fish from Kettle Creek. It is interesting to note that the period of most rapid growth in length of yearling brown trout coincides with the period of increase in condition of the fish. When the condition began to decrease in the summer, growth also decreased, as was reported by Brown (1946b).

Although seasonal changes in condition and in growth seem to be well established for wild populations of this species, no detailed explanation of their cause is presently available. Brown (1946c) has illustrated the complex interaction of food and temperature and behavior on the various physiological activities of brown trout under controlled conditions in the laboratory. There is little reason to believe that the situation is less complex in nature.

GROWTH IN WEIGHT

In most previous studies, growth of fishes has been reported as increment of growth in length. For some purposes it is more useful to analyze growth in terms of weight changes. Minot (1891) is usually credited with being the first to employ percentage rates of growth in weight to describe the changes associated with age in guinea pigs. Brown (1957) reviewed the use of such weight analyses under terms of specific, incremental, geometric, instantaneous, or multiplicative growth rate. In this study we have used a slight modification of the analysis suggested by Brown (1946a), which defines the specific growth rate as the percentage increase in weight per day relative to the weight at the beginning of the period in question, that is:

$$G = \frac{\log e\ Y_T - \log e\ Y_t}{T - t} \cdot 100.$$

where G = specific growth rate, Y_T = weight at time T, Y_t = weight at time t, and T is later than t, measured in days.

Sufficient data are available only from Spruce Creek to analyze changes in weight throughout the first 2 years of life of the brown trout. Since the young fish were not weighed in the field, the weights were computed from the combined data of the length-weight relationship and changes in condition of the yearling trout. It is only necessary to assume, in this case, that the seasonal changes in condition of the young fish do not differ greatly from those of the yearling fish.

The specific growth rate of brown trout in Spruce Creek declined very rapidly during the first year of life from a high of more than 5.5 percent of their body weight per day to small negative values in November and December (Figure 3). The apparent increase in specific growth rate in May of the first year may not be a real increase because there is a bias caused by continued recruitment of small fish into the population at this time (Table 4).

During the second year of growth, there is a rapid increase in specific growth rate to a high of about 3.0 percent of the body weight per day followed again by a decrease to small negative values in November. The marked deviations in specific growth rate of short time periods from an apparent smooth curve cannot be entirely explained as due to random variation, although the method of calculating specific growth rates for short time periods exaggerates the random variation found in the actual weight values from one collecting period to the next. Growth in weight for this wild population may not necessarily occur as a uniform function with time, but possibly as an interrupted series of rapid growth pulses as was found for brown trout held under constant temperature conditions (Brown, 1946b).

The marked seasonal change in specific growth rate of the trout in Spruce Creek is similar to that reported by Allen (1951) for the Horokiwi Stream, New Zealand. Spruce Creek fish, however, decrease to a much lower rate of growth in the winter than do the fish in the Horokiwi. It appears that both the Spruce Creek and Horokiwi populations of trout have a similar growth capacity which is expressed as maximum growth rates associated with a particular size of fish. The difference in total length or weight noted between the two populations at the end of the year probably is caused by the Spruce Creek fish growing at a much slower rate over a larger part of the growth period (Table 4).

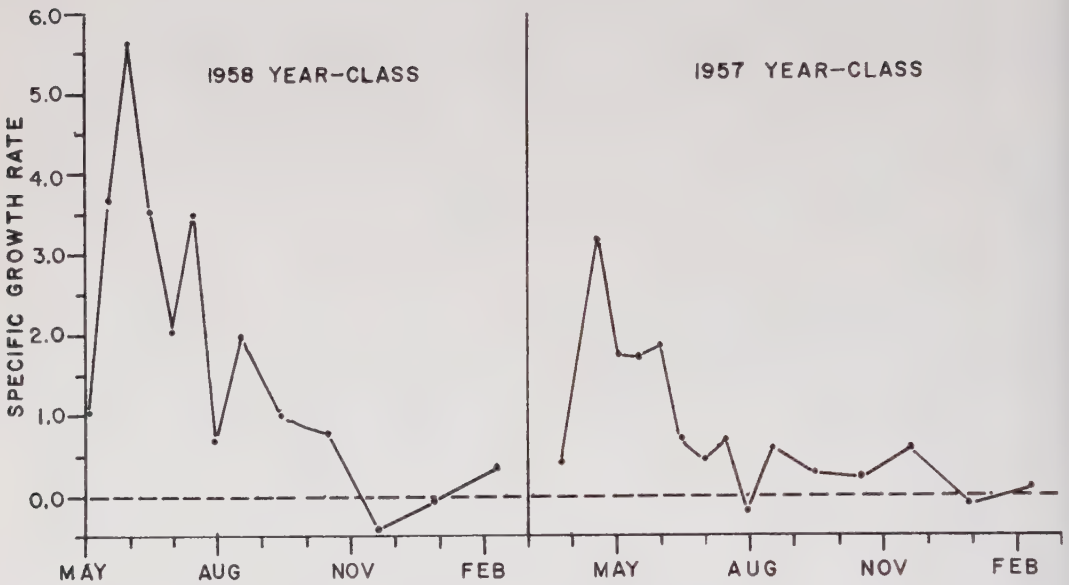

FIGURE 3.—Specific growth rate in weight of brown trout in Spruce Creek from March 7, 1958, to February 28, 1959. Rates are expressed as percentage of body weight per day.

DISCUSSION

The brown trout has been studied for many years in different parts of the world, yet only recently have adequate methods for detailed ecological work on wild populations of this species been available. Any attempt at the present time, therefore, to describe the exact cause-and-effect relationship between environmental factors and growth must include a large measure of speculation. The necessity for measuring many aspects of the environment simultaneously to obtain an understanding of the population dynamics of this fish has been demonstrated by Allen (1951). Although such information is difficult to obtain, it is needed if wild populations are to be managed in a practical manner.

The relationship between total alkalinity of a stream and trout production remains largely unknown, because there is a difference in the interactions of environmental factors on various trophic levels in the food chain (Frost, 1945). Moderately alkaline streams are usually more productive than soft waters, but the additional productivity may sometimes be utilized by competing species of fishes rather

TABLE 4.—*Specific growth rate in weight of brown trout in Spruce Creek during the period March 7, 1958, to February 28, 1959—expressed as percentage increment per day*

Period	1958 year class		1957 year class	
	Weight at start of period (grams)	Specific growth rate	Weight at start of period (grams)	Specific growth rate
March 7–April 10	—	—	12.8	0.40
April 11–April 24	—	—	14.7	3.14
April 25–May 8	0.27	1.01	22.8	1.72
May 9–May 23	0.31	3.67	29.0	1.70
May 24–June 6	0.54	5.60	37.4	1.83
June 7–June 20	1.18	3.51	48.3	0.68
June 21–July 6	1.93	2.03	53.1	0.44
July 7–July 20	2.67	3.47	57.0	0.65
July 21–August 1	4.34	0.68	62.4	−0.22
August 2–August 28	4.71	1.95	60.8	0.58
August 29–September 27	7.98	0.96	71.1	0.26
September 28–October 31	10.65	0.76	76.9	0.20
November 1–December 3	13.76	−0.43	82.2	0.55
December 4–January 19	11.93	−0.09	98.4	−0.13
January 20–February 28	11.44	0.35	92.7	0.04

than by the trout. In the three streams studied in Pennsylvania, a combination of high alkalinity and little competition from other fish in Spruce Creek was coincident with a faster growth rate of the trout when compared with the other two streams of low alkalinity and high competition from other fish species.

The fluctuations in growth of trout from one year to the next are apt to be of lesser magnitude than differences in growth of the trout from different streams (Cooper, 1953), or even different sections of the same stream (Allen, 1951). In Spruce Creek, the first-year growth of both the 1957 and 1958 year classes was almost the same, which supports this idea. If these data can be substantiated by further observations, it will not be necessary to collect data over a long series of years from the same stream to measure annual variability and to obtain a measure of growth rate of sufficient accuracy for management purposes.

Studies of changes in growth rate of trout within a year can be of great value in predicting the time of year when the maximum biomass of the population is reached. If seasonal changes in growth rate are great, and follow a typical pattern such as presented here for the brown trout and for other closely related species such as brook trout and rainbow trout (Cooper, 1953; Burdick and Cooper, 1956), the growth curve must necessarily approximate the biomass rate-of-change curve because there is a comparatively uniform mortality rate throughout the year.

Seasonal growth studies also provide the information necessary to determine the recruitment in a sport fishery if adequate information on the variability of size of the fish in seasonal samples is obtained. It appears that under a minimum size limit of 6 inches now in effect in Pennsylvania, most of the brown trout in the three streams studied are available to the fisherman as legal-sized trout by July of their second year of life. Since only a few males and almost no females are mature at the end of 2 years of life in such streams[2], the possible effects of fishing on the depletion of spawning stocks should be investigated.

Once the general form of the biomass curve, or growth curve, is known, the fishery manager may devise the best regulations for permitting the optimum yield of the fishery, after determining the desired characteristics of the yield in terms of greatest total weight, greatest number of trout, greatest number of large fish, or maximum recreation.

Suitable procedures for determining regulations aimed at obtaining the desired level of utilization of a fishery have been given by Ricker (1945) and Allen (1954). Since these procedures involve the collection of growth data such as presented here as well as information on the relationship between fishing intensity and stock density on total yield, there have been few instances where such procedures have been applied to the actual management of wild populations. The general tendency of management agencies has been to ignore the contribution of wild populations to the sport fishery and to concentrate their efforts of fish culture and public information on a put-and-take stocking program as a means of mollifying the public. Such a program neglects the management of the major source of trout to the angler, the natural populations. It is suggested that more information should be obtained on the population dynamics of natural fish populations, and that the results of such studies should be used to a greater extent in determining fishing regulations.

[2]James T. McFadden, personal communication.

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The Stoneroller, *Campostoma anomalum* (Rafinesque), in Great Smoky Mountains National Park

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ABSTRACT

The stoneroller *(Campostoma anomalum)* is one of the more important fish in Great Smoky Mountains National Park because of its abundance and habits. Although esteemed locally as a food and a bait fish, the stoneroller is exploited but little since the fishing regulations which govern the utilization of game fishes afford it a large measure of protection. Distribution is controlled by gradient with an upper limit of 4.4 percent. Stonerollers limit reproduction of rainbow trout *(Salmo gairdneri)* by destroying trout redds. Artificial reduction of stoneroller populations is not considered a necessary management procedure.

INTRODUCTION

In the course of investigations on trout in Great Smoky Mountains National Park, attention was drawn to the stoneroller because in some watersheds this minnow outnumbers and outweighs all other species of fish combined. Its size, up to 11 inches total length, places it among the larger fishes of the streams. Furthermore, because it is locally favored as a food and a bait fish, there is some demand by fishermen that the stoneroller be given specific consideration in the regulation of the Park fishery resources. As studies on the fishery progressed, it became apparent that rainbow trout, the principal game fish of the Park, is relatively scarce in those sections of streams where stonerollers are numerous. Observations were made, therefore, to determine the influences, if any, that the minnow exerts on the trout.

The taxonomic status of the stoneroller was not investigated, although such a study would be justified. Ross (1958) has reported four races of the species in New York and Pennsylvania. He is of the opinion that the stoneroller of the upper Tennessee River system, including Park waters, may prove to be another race.[1] The species *Campostoma anomalum* is widely distributed in about two-thirds of the United States. Its range extends from the St. Lawrence River southward to northern Alabama, excluding the extreme southeast, and westward to Wyoming and Texas (Dobie *et al.*, 1956). There are two to five subspecies reported (Trautman, 1957; Hubbs and Lagler, 1958). Throughout its range, the stoneroller is considered to be a fish of creeks and small rivers, with a preference for clean bottoms of rubble, gravel, or sand. It is taken only occasionally in large rivers and rarely in lakes. In the vicinity of Great Smoky Mountains National Park, the stoneroller is known more commonly as the hornyhead. It is seldom confused with the river chub *(Hybopsis micropogon)*, which is called the hornyhead in some regions but is known as the knottyhead in the Smokies.

[1]Personal communication, October 30, 1959.

DISTRIBUTION IN THE PARK

The stoneroller occurs in every watershed in the Park. Large numbers have been collected in the past 7 years during repeated surveys of fish populations. The survey methods and gear were described by Lennon and Parker (1957). Careful estimates were made of the numbers and pounds of stonerollers and of other species per acre of stream. The stoneroller is usually found from the Park boundary to elevations upstream as high as 3,140 feet above sea level (Table 1). Stream gradient appears to limit its distribution. In the lower 7 miles of Big Creek, the stream is rough with a gradient of 222 feet per mile, and the stoneroller is abundant. In the upper 5 miles of main stream, the gradient increases to 440 feet per mile and the stoneroller is absent. In Little River, the lower 18 miles

TABLE 1.—*The distribution of the stoneroller with reference to elevation and gradient in selected streams of Great Smoky Mountains National Park*

Stream	Elevation of stoneroller sections		Gradient (feet per mile)		Miles of main stream	
	Lower limit	Upper limit	Stoneroller section	Above section	Stoneroller section	Above section
Big Creek	1,540[1]	3,140	222.2	440.8	7.2	4.9
Bradley Fork	2,158[2]	2,640	150.6	363.8	3.2	5.8
Cosby Creek	1,650[1]	2,040	229.4	900.0	1.7	2.4
Deep Creek	1,792[1]	1,970	68.5	250.5	2.6	11.5
Hazel Creek	1,710[1]	2,260	141.0	334.1	3.9	8.8
Little River	1,080[1]	2,720	89.6	579.2	18.3	4.8
Porters Creek	1,680[2]	1,850	170.0	380.4	1.0	4.6
Middle Prong, Little River	1,110[2]	1,600	119.5	447.7	4.1	6.7
Oconaluftee River	1,970[1]	2,800	98.8	440.9	8.4	4.4
Little Pigeon River	1,380[1]	1,800	110.5	517.1	3.8	5.8
West Prong, Little River	1,120[2]	1,800	170.0	600.0	4.0	4.0
West Prong, Little Pigeon River	1,330[1]	1,750	107.7	323.2	3.9	8.2
Total	—	—	—	—	62.1	71.9

[1]Elevation at Park boundary in feet above sea level.
[2]Elevation at mouth in Park in feet above sea level.

have an average gradient of 89.6 feet per mile, and the average population of stonerollers has been estimated at 1,151 fish, or 71 pounds, per acre (Table 2). The average gradient of the upper 5 miles of main stream is 579.2 feet per mile and the stoneroller is not present.

Twelve of the more thoroughly surveyed streams have a combined total length of 134 miles within the Park. Of this total, the 62 miles inhabited by the stoneroller have an average gradient of 2.7 percent, while the remaining 72 miles have an average gradient of 8.8 percent. It appears that an average gradient of 4.4 percent (230 feet per mile) is the upper limit for the stoneroller. The species cannot, however, be considered a quiet-water fish which is confined mostly to pools and riffles. Within its sections of the streams, many stonerollers are taken in rough, steep cascades which most of the other cyprinids avoid.

There are two factors in addition to gradient which may contribute to the exclusion of the stoneroller from uppermost sections of the streams. First, the periphyton on which the stoneroller feeds is less abundant in the upper and steeper sections and second, the water in upper sections is more acid than in lower sections. Measurements of pH in the headwaters are as low as 5.2, whereas in stoneroller waters downstream they are from 6.6 to 7.0.

By far the greatest concentration of stonerollers found anywhere in the Park during the past 7 years occurred at one of the survey stations on Little River in 1956. The estimate was 9,528 fish, or 522 pounds, per acre. The populations at several other stations on the same stream ranged from 5,816 to 7,121 fish per acre. The estimates of stonerollers at stations on Porters Creek and Little Pigeon River have been as high as 2,750 fish and 3,197 fish per acre, respectively. The estimates are considered to be conservative. The primary objective of electrofishing at the survey stations was to collect trout, and where stonerollers were especially numerous, it was

TABLE 2.—*Numbers and pounds per acre of stonerollers, rainbow trout, eastern brook trout, and other species in selected streams of Great Smoky Mountains National Park*

[Estimates based on data from surveys in 1954 and 1955.]

Stream	Stoneroller		Rainbow trout		Brook trout		Other species		All species	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Big Creek	699	55	1,097	79	94	3	149	4	2,039	141
Bradley Fork	284	17	745	52	34	1	791	11	1,854	81
Little River	1,151	71	349	30	—	—	1,024	27	2,524	128
Little Pigeon River	1,112	67	414	29	—	—	1,304	34	2,830	130
Porters Creek	793	55	240	14	—	—	935	20	1,968	89
West Prong, Little Pigeon River	912	48	90	9	279	9	1,043	11	2,324	77

mpossible for the crew to capture all that ere observed.

The effects of reducing stoneroller popula- ons were observed in portions of several reams. The same sections of the streams ere surveyed annually from 1954 through 958, and between 60 and 90 percent of the toneroller present at each survey were re- oved. In one section of Little River there ere 2,729 stonerollers per acre in 1954, 655 1956, and 123 in 1958. The average length nd weight of specimens taken in the section fter 1954 gradually increased. In 1954 the sh averaged 5.6 inches in total length and 5 grams in weight; in 1956 the averages ere 5.8 inches and 43 grams; and in 1958 ey were 7.2 inches and 83 grams. In a sec- on of Porters Creek the 1954 population was 750 stonerollers per acre; in 1956 it was 41; and in 1957 it was 473. In a section of ittle Pigeon River there were 1,830 stone- ollers per acre in 1954, 427 per acre in 1956, nd 172 per acre in 1958. The fish in these ections also increased in average length and eight as the total populations were reduced. hese results indicate that the abundant pop- lations can be cut down substantially by ex- loitation. They show, too, that there was lit- e movement of stonerollers into the harvested ections from the adjacent upstream and ownstream sections.

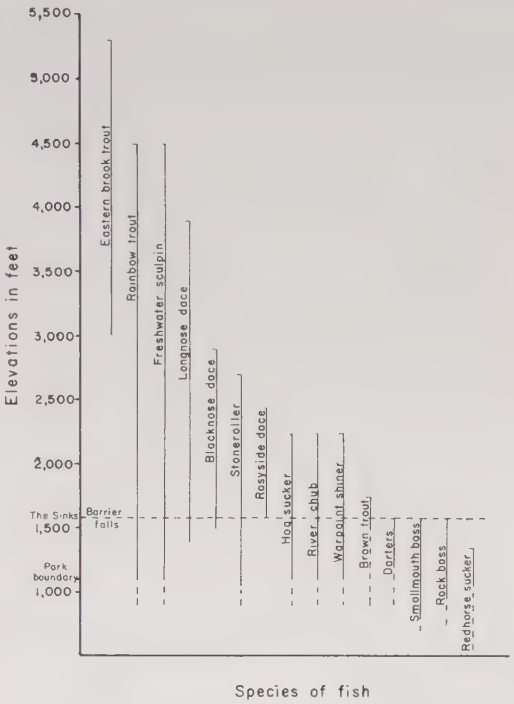

FIGURE 1.—The distribution of the stoneroller and other selected species by elevation in Little River. There are approximately 23 miles of fishable water between the Park boundary and the upper limit of brook trout distribution. The solid lines indicate the ranges within which the species were collected during recent surveys. The broken lines denote the ranges within which the species are known to occur.

ASSOCIATIONS WITH OTHER FISHES

The stoneroller is associated with many ther species of fish in Park streams (Table). A thorough check throughout 23 miles of ittle River demonstrated, however, that the ertical distribution of the stoneroller is reater than for most of the other species. nly blacknose dace *(Rhinichthys atratulus)*, ongnose dace *(Rhinichthys cataractae)*, scul- in *(Cottus carolinae)*, rainbow trout *(Salmo airdneri)*, and brook trout *(Salvelinus fon- inalis)* occur at higher elevations (Figure 1). n general, the largest numbers of the stone- oller were found from the middle to the op of its range, in waters where it was rela- ively free from association with many species r from piscivorous species. The large major- ty of rainbow trout in the streams were too mall to be considered piscivorous.

The stonerollers in Little River are most bundant from The Sinks (elevation: 1,545 eet) to a point 10 miles upstream (elevation: 2,500 feet). The Sinks include a barrier falls 15 feet high which marks the upstream limit for smallmouth bass *(Micropterus dolomieui)* and rock bass *(Ambloplites rupestris)*. These centrarchids appear to control the numbers of stonerollers, and at survey sites below the falls where smallmouth bass were common. the stonerollers were relatively scarce. In one survey, for example, there were 1,084 stone- rollers per acre immediately above the falls, but only 40 fish per acre below them where smallmouth bass numbered 78 per acre. The same situation was noted in other streams in which smallmouth bass and rock bass occur.

SIZES AND MATURITY OF THE STONEROLLER

The ranges in length of stonerollers in dif- ferent localities vary considerably. Kirsch (1893) listed 4 inches as the maximum length of stonerollers collected in Clinton County, Kentucky. Evermann and Clark (1920) re- ported a range up to 9 inches for fish in the

Lake Maxinkuckee area in Indiana. Hubbs and Cooper (1936) pointed out that males grow to a larger size than females. They stated that the maximum length for males in Michigan is about 6 inches, and less than 5 inches for females. Trautman (1957) listed a maximum length of 7 inches for the Ohio stoneroller *(Campostoma a. anomalum)*, whereas Eddy (1957) gave 8 inches as the maximum length for the species in general.

Among the stonerollers examined in Great Smoky Mountains National Park, the largest male was 11.3 inches in total length and the largest female was 7.4 inches long. In a group of 580 specimens collected in March 1959 in West Prong, Little River, sex was determined in 501 over 3 inches long. The 218 males ranged from 3.2 to 9.4 inches (average, 5.9 inches) and the 283 females from 3.0 to 7.4 inches long (average, 5.1 inches). Thirty-two percent of the males, but only 3 percent of the females, were 7 inches or longer. The ratio of sexes among the 501 fish was 44 percent males and 56 percent females.

The length-frequency distribution of 1,719 stonerollers which were measured during fall surveys on Little River in 1955-58 had a range of 1.8 to 8.3 inches, with peaks in the 2.0- to 2.9-inch and 4.0- to 4.9-inch groups (Table 3). The peaks in distribution of the 580 fish collected in West Prong, Little River in March 1959 occurred in the 2.0- to 2.9-inch and 5.0- to 5.9-inch groups. The range in length of fish in this collection was 1.5 to 9.4 inches.

The fact that 12 percent of the stonerollers in the late-winter collection from West Prong, Little River were less than 3 inches long indicates that the fish does not grow fast. The data on length-frequency of specimens from both streams also show that less than 15 percent of the fish exceed 7 inches in length.

Although the 501 stonerollers from West Prong, Little River were sexed shortly before the spawning season when sex and state of maturity were readily apparent, there were great differences in the proportions of immature and mature fish in both sexes (Table 4). Of the 218 males, 72 percent were immature. In contrast, only 10 percent of the females were immature. The immature males were up to 8.2 inches long, but the immature females did not exceed 5.2 inches. The reason for the high proportion of immature males in the sample is unknown. Not only were the testes undeveloped, but there were no nuptial tubercles nor other secondary sex characteristics. The 501 fish were collected in pools and riffles in the upper and lower sections of the stream to preclude any selectivity in size, sex, or maturity. There appeared to be no intergradation between immaturity and maturity in the specimens, and it is therefore unlikely that any number of the immature fish would have matured within the month remaining before the spawning season.

AGE OF STONEROLLERS

Hubbs and Cooper (1936) aged a few stonerollers by microscopic examination of the scales and estimated that the minnow reaches maturity during the second or third summer. Lewis and Elder (1953) aged stonerollers by means of length-frequency curves. In the present study the disparity in length between males and females made the length-frequency method less exact than the scale method. Annuli, with the exception of some of the first ones, were distinct and were not complicated by spawning checks. Observations on many collections and a comparison

TABLE 3.—*Length-frequency distribution of stonerollers collected in Little River in 1955-1958, and in West Prong, Little River in 1959*

Stream and year	Length group (inches)									Total
	1.0–1.9	2.0–2.9	3.0–3.9	4.0–4.9	5.0–5.9	6.0–6.9	7.0–7.9	8.0–8.9	9.0–9.9	
Little River										
1955	1	19	20	70	51	55	11	1	0	228
1956	4	102	15	164	123	72	48	16	0	544
1957	0	1	6	9	3	8	9	4	0	40
1958	25	130	32	359	285	64	12	0	0	907
Total	30	252	73	602	462	199	80	21	0	1,719
West Prong, Little River										
1959	10	60	47	151	165	68	61	15	3	580

TABLE 4.—*Percentage of immature and mature males and females in a sample of 501[1] stonerollers collected in West Prong, Little River—March 1959*

Sex and maturity	Length group (inches)							Number of fish
	3.0–3.9	4.0–4.9	5.0–5.9	6.0–6.9	7.0–7.9	8.0–8.9	9.0–9.9	
Males								
Immature	13	24	29	15	15	4	0	157
Mature	3	13	5	10	49	15	5	61
Total	11	21	22	14	24	7	1	218
Females								
Immature	41	55	4	0	0	0	0	27
Mature	2	35	45	15	3	0	0	256
Total	5	38	41	13	3	0	0	283

[1]Males, 44 percent; females, 56 percent.

of length-frequency curves with scale data lead us to believe that the scale method of aging stonerollers from the Park streams is valid.

Three groups of fish were collected and aged in the fall of 1958. Thirty-nine fish from Big Creek ranged in age from 0 to 5 years and in length from 2.3 to 8.9 inches (Table 5). Fifty-two fish from Cosby Creek were 0 to 5 years in age and 3.9 to 8.1 inches in length. The 183 fish from Little River ranged from 0 to 4 years old and from 2.4 to 7.5 inches long.

Age and sex were determined for 143 stonerollers which were collected in the West Prong, Little River in March 1959 (Table 6). The 71 males were 2 to 6 years old and were 3.5 to 8.5 inches long. The 72 females were 2 to 5 years old and were 3.6 to 6.1 inches long. Of the males, only 32 percent were mature. Among the females, 96 percent were mature. None of the 2-year-old stonerollers were mature. Of the 3-year-olds, most of the males were immature, but most of the females were mature. More than half of the 4-year-old males were immature, but all the females of that age were mature. All 5-year-old fish of both sexes were mature. On the basis of the small sample of 143 fish, it appears that the majority of stonerollers reach maturity in their third or fourth year of life. Some males do not mature until their fifth year. No explanation can be offered for the relative tardiness of males in reaching maturity.

INTERSPECIFIC SPAWNING RELATIONSHIPS

The stoneroller spawns in the spring. Langlois (1937) reported details of the process, and Hubbs and Cooper (1936) noted that among the minnows, the stoneroller shows the most extreme development of the nuptial tubercles. It is this striking development of tubercles that causes the fish to be called the hornyhead in the Smokies. Extensive spawning activities were observed in the Park in 1958 and 1959. Many fish constructed nests in gravel in the tailwater of pools and at the heads of riffles in the main stream and in gravel areas of small tributaries. Where fish were abundant, they swarmed over spawning beds in large numbers and markedly altered the stream bottom during the construction of overlapping nests. The nests of early spawners were often destroyed by later spawners.

The most important aspect of stoneroller spawning in many of the Park streams is its effect on the rainbow trout. Surveys have dis-

TABLE 5.—*Numbers and lengths of fish in each age group of stonerollers captured in Big Creek, Cosby Creek, and Little River in the fall of 1958*

Age group	Big Creek		Cosby Creek		Little River	
	Number	Length (inches)	Number	Length (inches)	Number	Length (inches)
0	2	2.3	1	3.9	7	2.4–3.2
I	3	3.1–4.1	12	3.5–5.1	17	3.4–4.6
II	6	4.6–5.2	15	4.0–5.7	66	4.2–6.5
III	11	5.0–8.1	15	5.3–7.5	70	4.8–7.3
IV	13	6.5–9.4	6	6.4–7.7	23	6.0–7.5
V	4	6.8–8.9	3	7.5–8.1	0	—
Total	39	—	52	—	183	—

TABLE 6.—*Number and length of 143 immature and mature stonerollers of both sexes in each age group taken from West Prong, Little River, in March 1959*

Age group	Males				Females			
	Immature		Mature		Immature		Mature	
	Number	Length (inches)	Number	Length (inches)	Number	Length (inches)	Number	Length (inches)
II	4	3.5–4.0	0	—	1	3.6	0	—
III	28	3.6–7.0	5	4.0–5.6	2	4.0–4.2	30	3.6–5.9
IV	16	5.0–7.5	12	4.0–8.5	0	—	34	4.5–6.1
V	0	—	4	7.0–7.4	0	—	5	5.0–5.8
VI	0	—	2	7.0–7.1	0	—	0	—
Total	48	—	23	—	3	—	69	—

closed that the reproduction of rainbow trout is small in stream sections where stonerollers are numerous, but that the numbers of mature trout present in these sections are generally adequate for good reproduction. An attempt was made, therefore, to determine the factor or factors which limit the reproduction of the trout in stoneroller sections of streams.

In the spring of 1958 selected rainbow trout redds in Little River, above and in stoneroller sections, were kept under daily observation. Trout spawned in March, and the redds in both sections contained good quality, viable ova. In the latter half of April, before the trout had hatched in the stoneroller section, swarms of the minnow congregated over the same spawning beds that the trout had used. The nest-building activities of the minnows soon obliterated all traces of the trout redds, and trout ova could no longer be found at the sites of deposit. Subsequently, only one trout fry was observed in a long section of stream where trout redds had been numerous.

In contrast, a large hatch of trout occurred in late April in the stream above the stoneroller section. Numerous sac-fry and free-swimming fry were observed in the following weeks. Surveys with electrofishing gear in the fall of 1958 confirmed the observations made during the spawning season. Young-of-the-year trout were abundant in the upper section of Little River, but were relatively scarce in downstream waters where stonerollers are numerous. There were, however, increases in the numbers of small trout at those survey stations where stonerollers had been harvested experimentally during preceding years.

Observations on Abrams Creek in the spring of 1958 confirmed the findings made on Little River. The lower 14.5 miles of Abrams Creek were treated with rotenone in 1957 and restocked with rainbow trout in the same year (Lennon and Parker, 1959). The trout spawned in early March 1958 and an excellent hatch occurred throughout the reclaimed section in the last few days of April. Large numbers of fry were easily observed in the big water. Since physical conditions for trout reproduction in Abrams Creek were considered to be less favorable than in the stoneroller section of Little River, it appeared that the stoneroller had been responsible for the poor reproduction of trout in the latter stream.

The spawning of rainbow trout and stonerollers was observed again in Little River in 1959. The results, although less clear cut, were similar to those of the preceding year. The trout spawned in early March, but the cold weather which followed delayed hatching until May. Most of the redds built by trout in the stoneroller section were destroyed by the minnow during its spawning in late April and early May.

There is no doubt that the stoneroller competes with the rainbow trout for spawning beds in sections of many streams in the Smokies. The stoneroller spawns later than the trout, but usually before the trout ova hatch. Where the minnow is abundant, the reproduction of trout is severely reduced by the destruction of its redds. Reighard (1910) reported a related situation. He observed that spawning stonerollers often destroy the nest of creek chubs.

SIGNIFICANCE OF THE STONEROLLER IN PARK STREAMS

The lower sections of some of the principal Park streams have been stocked with

catchable-sized rainbow trout for more than a decade. Studies have shown that the stocking was necessary to augment the numbers of wild trout available to anglers. The same streams, however, have excellent numbers of wild trout upstream in sections which are accessible and as heavily fished as the lower sections. Observations on the chemistry and seasonal temperatures of the water in the lower sections of the streams failed to provide a reason for the shortage of wild trout. Competition with smallmouth bass and rock bass did not appear to be a factor, since the centrarchids occur in only a few of the streams. Finally, the growth and survival of marked, fingerling rainbow trout which were stocked experimentally demonstrated that the lower sections are suitable for trout. The limiting factor appears to be severe competition between rainbow trout and stonerollers for spawning grounds. The large populations of the minnow, therefore, apparently limit the production of rainbow trout in many Park waters. This situation is aggravated by the fact, as determined by mark-and-recapture studies, that few trout other than larger and older fish migrate downstream into the stoneroller sections. It appears that trout populations in the stoneroller sections can be improved only by stocking or by reducing the numbers of the minnows.

From the standpoint of fish management, it is significant that since the stoneroller is favored as a table fish and a bait fish, a great utilization of the species could be fostered easily. In eastern Tennessee the minnow is especially prized as a food fish (Lawrence, 1960). In respect to the popularity of the fish in the Smokies area, the Tennessee Game and Fish Commission stated in its folder *Tennessee Fish and Where to Catch Them* that: "There are fishermen who are so particular about what they eat that they will throw back the trout and keep the hornyheads."

Fishermen prefer to catch stonerollers with bits of worm on small hooks when large numbers of the fish are congregated over spawning beds. The fishing season in the Park, however, opens in mid-May, after the spawning period, and only artificial lures are permitted. Although the minnow can be caught during the summer with small wet flies, fished slowly and deeply, many fishermen feel that the Park regulations deprive them of a desirable fishing opportunity.

The stoneroller is utilized also as a bait fish in the Smokies region, and Kuhne (1939) rated it as an excellent bait in Tennessee. It is popular elsewhere and has been mentioned as one of the best baits for bass (Dobie *et al.*, 1948), for walleye (Evermann and Clark, 1920), and for catfish (Harlan and Speaker, 1956). It can be raised in bait production ponds (Langlois, 1937), and it is a good aquarium fish (Forbes and Richardson, 1920). The collection of fish for bait from Park waters, however, is prohibited.

Despite its competition with the principal game fish and its value as a food fish and bait fish, the alteration of fishing regulations in the Park to permit a greater harvest of stonerollers, or the application of partial or vigorous control measures, is considered unnecessary. In fact, control of the minnow would be inconsistent with National Park Service policy which provides primarily for the protection of all native fishes.

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The Development of Sport Fishery Resources on Indian Lands in the Southwest

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ABSTRACT

Waters on Indian lands have been generally unavailable to the public for sport fishing in the Southwest. The Indian tribes that have jurisdiction over tribal lands and waters are recognizing the economic value and employment potential to be derived from sport fishery resources. Programs are now being formulated in cooperation with the Bureau of Sport Fisheries and Wildlife of the U. S. Fish and Wildlife Service to develop these fisheries. Tribal funds are being used to develop fishing waters and facilities for the use of the public. Some problems encountered in developing sport fisheries on Indian lands are discussed. A successful program on the Fort Apache Indian Reservation is described.

In the western states of Arizona, New Mexico, Colorado, Utah, and Wyoming, comprising part of Region 2 of the Bureau of Sport Fisheries and Wildlife of the U.S. Fish and Wildlife Service, there are approximately 31.5 million acres of Indian lands. On these lands there are an estimated 1,815 miles of streams and 10.000 surface acres of lakes that provide suitable habitat for game fish. Until recently much of this land and water was generally unavailable for sport fishing by the general public. Much of this water was also relatively non-productive because there was a lack of intensive fishery management. Although the estimates of waters suitable for sport fishing given above may not be impressive when compared with those in other parts of the country, they are important in the arid Southwest where water is relatively scarce and the human population is increasing at a very rapid rate. Studies by this Bureau for the Indian tribes have shown that in most of the Southwest there is a large unsatisfied demand for sport fishing opportunities.

Jurisdiction over sport fisheries on Indian lands is vested in the Indian tribes. The states do not have jurisdiction and, in general, do not engage in fishery programs on Indian reservations. Fishery management assistance on Indian reservations is provided by the Branch of Fishery Management Services of the Bureau of Sport Fisheries and Wildlife. The required fish for stocking Indian waters are provided by the Bureau's national fish hatchery system. Fishery programs of the Bureau are undertaken under an agreement between the Bureau of Indian Affairs and the Fish and Wildlife Service. In addition, the Bureau has entered into agreements with several Indian tribes. Agreements with other tribes are now pending. These tribal agreements in effect provide for technical assistance in the management of sport fisheries and the stocking of fish in accordance with management needs on reservation waters by the Bureau. They also provide that the tribes shall establish regulations for the conservation of sport fisheries. Insofar as possible these regulations shall be consistent with state regulations. These agreements also serve as a statement of the intent and interest of the tribe in the development of sport fishing resources. Tribal policy toward sport fisheries is established in these documents.

On Indian reservations the tribal council, elected by tribal members, is the governing body, and its chairman is the chief executive of the tribe. The tribal council has the authority to promulgate regulations including those dealing with fishery matters and may engage in programs for the well-being of tribal members. Tribal courts deal with offenders who are tribal members, except in case of certain major crimes which are tried in Federal courts.

State laws and regulations generally do not apply on Indian reservations to tribal members. In practically every case, the tribal councils pass ordinances providing that all fishing on the reservation shall be in accordance with state regulations and that all non-tribal fishermen shall possess state fishing licenses. In some instances, tribal regulations pertaining to bag limits are more restrictive

than state regulations. All persons fishing on tribal lands must comply with tribal regulations. In some cases where fish and wildlife resources are important, tribal fish and game committees have been established to advise the tribal councils. In summary, on Indian reservations, tribal councils exercise authority similar to state governments in fishery matters. The Department of the Interior, through the Bureau of Indian Affairs in its trust capacity, provides general guidance and the Bureau of Sport Fisheries provides technical assistance and fish stocking on Indian reservations.

The concept of sport fishing was not a part of the culture of most Indian tribes in historical times. Several tribes, including the Navajos and the Apaches, had ancient taboos against the eating of fish. Although this attitude has now generally disappeared, Indians do relatively little sport fishing. Observations on the Fort Apache Indian Reservation have indicated that only about 1 percent of the fishermen are Indians. Where it is available, sport fishing is increasing in popularity as a recreation by Indians.

The idea that sport fisheries are valuable economic resources is just now coming to be understood by tribal leaders, largely as the result of activities of this Bureau. It is the possibility of economic return to the individual Indians and the tribes that makes possible the development of sport fishing programs. The Bureau's program of developing sport fishing on southwest Indian reservations began in a very limited way in the late 1930's on the Fort Apache Indian Reservation in Arizona. A national fish hatchery was established and fishery management biologists of the former Branch of Game-fish and Hatcheries of the Fish and Wildlife Service provided technical assistance. Far-sighted tribal leaders and Bureau of Indian Affairs officials initiated and enthusiastically supported the program. The motivation was economic. Tribal forestry income would soon be reduced as timber harvest approached a sustained yield level. The livestock industry had reached the limit of range-carrying capacity. Catering to sport fishermen who would fish the fine trout streams and small artificial lakes would provide cash income and employment to tribal members. This program has been so successful that it is serving as a model for other Indian tribes.

Some biological work and fish stocking have been underway on Indian waters for several years. With the creation of the Bureau's Branch of Fishery Management Services in 1957, the program was greatly accelerated. The program was further stimulated by the availability of tribal capital from gas, oil, mineral development, and other sources, which can be applied to fishery development activities. The bureau is now working with 18 Indian tribes in the Region in the development of sport fishing opportunities for the general public.

The decision to engage in a fisheries program is one which must be made by each individual tribe through its elected tribal council. As is the case with any government entity in a democracy, the tribal council must have the support of tribal members in order to prosecute successfully an endeavor such as a fishery program. A number of serious questions are involved. Some of the major ones are the following: shall the tribe encourage the entrance of non-tribal members upon the reservation; can available water supplies be made to serve both irrigation and fisheries; if not, what use of the water is best for the well-being of the tribe; will grazing or farming be adversely affected when land is taken for water improvements or resort sites; if so, how can existing landusers be relocated or adequately compensated? The problem of money must also be considered. Are finances available to develop a sport fishery and if so, at what level? There is, of course, the constant problem of whether to invest tribal capital in fishery development or to use it for other tribal enterprises. The question of whether tribal lands and waters have a potential and the extent of that potential is answered by this Bureau. Fishery management reports are supplied to the tribes setting forth the potential both from a biological and an economic point of view.

The speed with which the programs move ahead varies with the political and economic situation on each reservation. Tribes that possess aggressive and competent leadership, capital available for development, and a need for job opportunities are proceeding rapidly in developing sport fishing resources.

The income to the tribes from this program will be from providing goods and services to the fishing public. Fees for fishing permits are very reasonable. The Fort Apache Tribe

charges 60 cents the first day and 30 cents for each additional, consecutive day. Fishing-permit fees are used to offset the cost of fire protection, safety, law enforcement, some road maintenance, and the development of camping and picnicking sites. Resort operations, including stores, gas stations, lodges, motels, boat rentals, trailer parking, and improved camping areas, will be the major income-producers and will provide jobs for tribal members. The leasing of tribal lands for summer-home sites will also provide income and employment.

Practically every type of fishery management problem is encountered on Indian waters of the Southwest. On the credit side, almost all waters suitable for fish are very high in fish-producing capacity. On the debit side, most of the artificial impoundments, which in many reservations provide the only fishing waters, were constructed for irrigation purposes and were not designed to provide optimum conditions for fish. This Bureau is providing criteria for improvements, both in construction and operation, to make such waters serve both fish-production and irrigation needs. Impoundments that are properly constructed and operated can be managed more efficiently and produce more fishing with the least cost. These waters are given priority over streams. Except in certain remote areas, the streams are now utilized heavily. The opportunities for significant expansion of the fisheries lie in the creation of new impoundments designed for fish production and the improvement of existing ones. In New Mexico and Arizona the general scarcity of water and recurring periods of drought complicate fishery management. It is this scarcity of water, however, which makes the limited fishing water so valuable and effective fishery management imperative.

Most of the larger Indian reservations can produce a diversity of fishing. Several contain high mountain ranges with elevations up to 12,000 feet above sea level where considerable winter snow pack occurs. In New Mexico and Arizona, waters from 6,500 feet elevation and above have temperature conditions suitable for trout. In general, waters below this elevation are most suitable for warm-water fish production.

The most highly developed fishery program is on the Fort Apache Indian Reservation in Arizona, where in 1957 there were approximately 80,000 man-days of fishing. This use increased to 105,000 man-days in 1958. On the basis of present trends, over 150,000 man-days of fishing are expected in 1959. This fishery is in the high mountains and is developed approximately two-thirds on streams and one-third on impoundments. As the program grows, a greater percentage of the fishing effort will be upon impounded waters. Most of this fishery is for rainbow trout. The catch per man-hour of fishing was 0.77 in 1957 and 0.71 in 1958. Over 80 percent of the catchable trout stocked are returned to the creel. Water temperatures in some of the sections of streams rise to the critical levels during hot, dry summer periods. A close check is maintained of stream conditions and fishing intensity. In-season stocking of legal trout is carefully adjusted to these factors. Hawley Lake, a 250-surface acre impoundment, was built especially for fishing at a cost of $200,000 to the tribe. The lake produced an estimated 3,500 man-days of fishing the first weekend it was opened late in May 1959. During the entire year it provided approximately 55,000 man-days of fishing and 44,000 pounds of fish. This lake and all but the smallest impoundments are stocked with small fingerling rainbow trout.

The total sport fishing effort that was expended on Indian reservations in the Southwest is estimated to be more than 225,000 man-days for 1959. This estimate is arrived at from a study of permit sales, biologist creel checks, game warden checks, automobile counters, and general trends of such data gathered through the past few years. Except on the Fort Apache Indian Reservation, there has been no effort to advertise or to encourage additional fishing. Tribal progress for the most part is in the stage of policy consideration. The tribes are not anxious to bring in a hoard of fishermen until high-quality fishing and adequate facilities are available. Most of the fishery management work of this Bureau on Indian lands is in the reconnaissance stage. The problem at this time is to record general information on existing fishing waters and to determine development potentials. Much effort is being expended by our biologists, in cooperation with the Bureau of Indian Affairs officials, in establishing personal contact with tribal leaders and explaining and demonstrating opportunities for fishery development.

Observed and Calculated Lengths of Lake Trout *(Salvelinus namaycush)* in Cayuga Lake, New York[1]

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ABSTRACT

Back-calculated lengths of lake trout *(Salvelinus namaycush)* in Cayuga Lake, New York, were compared with empirical values. The body-scale relationship was sigmoid over a range of fish lengths of 6 to 26 inches; the method of back-calculation involved preparation of a body-scale ruler adapted for use on a conventional direct proportion calculating device. When compared graphically, calculated and observed mean lengths (through age VII) were in excellent agreement. Calculated data showed a significantly lower variance than observed.

INTRODUCTION

A preliminary inspection of body-scale relationship of lake trout *(Salvelinus namaycush)* from Cayuga Lake indicated it to be unusually complex. Royce (1943)[4] had already noted this fact for lake trout in other Finger Lakes of central New York, but was unable to pursue the problem because there were insufficient data. Information available from marked and unmarked lake trout in Cayuga Lake has been used to describe the body-scale relationship and check the accuracy of calculated growth. Details on the more general investigation are published elsewhere (Webster, Bentley, and Galligan, 1959).

Lake trout used in this study were taken in a graded series of gill nets (1½- to 3½-inch stretched mesh) in July and August, 1949-55. These catches were supplemented by fish taken by angling throughout the 1957 season, and by a sample of large trout from the spawning population in 1950. Many of the trout in the sample had been stocked as marked hatchery fish and were, therefore, of known age. In recent years over 50 percent of gill-net and angling samples have consisted of marked trout.

Scale samples were taken from the side of the fish between the dorsal fin and lateral line. Scale impressions were made in plastic and examined with a microprojector. The positions of scale margin and annuli were marked off on the edge of a card graduated in millimeters, and measurements were made along the anterior scale radius.

BODY-SCALE RELATIONSHIP

A scatter diagram of plottings of scale radius against the body length (Figure 1) shows the general relationship of the measurements. To summarize these data they were grouped into 0.5-centimeter intervals of scale radius (Whitney and Carlander, 1956). Class means of data summarized in this manner for the years 1950-52 and 1954-55 are given in Table 1. Scale measurements were incomplete for 1953 at the time of this study. Size-class means, plotted in Figure 2, indicate a regular curvilinear relationship between 6 and 22 inches, but a marked downward inflection of the curve occurs at 22-23 inches.

The inflected part of the curve was also checked against growth indicated on scales from large fish taken from the spawning population. The distribution of the class means, also plotted in Figure 2 (solid circles), is in agreement with the distribution of points representing summer data. The abrupt change in body-scale relationship coincides with a comparable inflection in the curve for growth of Cayuga Lake lake trout. Decrease in growth rate is coincident with the size (and age) at sexual maturity in Cayuga Lake (usually ages V and VI and is probably re-

[1]Study conducted as a class project in a course in fishery biology at Cornell University, 1956, under direction of senior author.

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[4]Royce, William. (1943) The reproduction and studies on the life history of the lake trout *Cristivomer namaycush namaycush* (Walbaum). Ph. D. dissertation, Cornell University, Ithaca, New York.

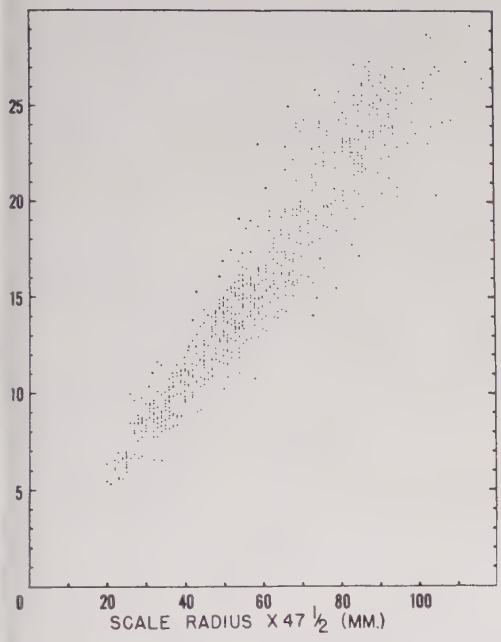

FIGURE 1.—Relationship of anterior scale radius and fork length of lake trout, Cayuga Lake.

ated to the nature of the food supply (Webster *et al.*, 1959).

The body-scale curve was subdivided into two components: (1) the regular curvilinear portion representing trout 22 inches in length; and (2) the inflection, representing larger size fish. A logarithmic transformation of the data over the range of 6 to 22 inches failed to yield a linear fit. An iterative method of curve fitting was attempted that consisted of subtracting a constant from the length before logarithmic transformation. The linear regression was then computed and the amount of variance due to linearity determined. A satisfactory fit was obtained when a constant of 2.0 was used. The equation for the line

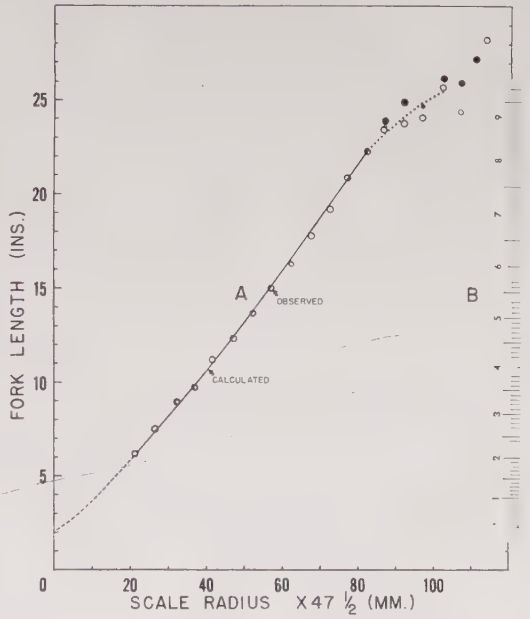

FIGURE 2.—A. Mean observed and calculated body-scale relationship of lake trout, Cayuga Lake. Open circles, observed data taken in summer gill-net samples, 1950-52, 1954-55; closed circles, collected autumn 1950. Dotted portion of curve fitted by eye; equation for balance of line in text. B. Body-scale ruler in position as constructed from body-scale graph. Graduations in fork length, labels in terms of scale radius.

TABLE 1.—*Mean fork length in inches and scale radius in millimeters for 1,384 lake trout, Cayuga Lake. Summer samples, 1950-52, 1954, 1955; fall samples, 1950. Data grouped by 5-millimeter scale intervals.*

Interval of scale radius (millimeters)	Summer data			Autumn data		
	Scale radius (millimeters)	Fork length (inches)	Number of fish	Scale radius (millimeters)	Fork length (inches)	Number of fish
20-24	21.8	6.10	21	—	—	—
25-29	26.9	7.55	47	—	—	—
30-31	32.3	8.94	89	—	—	—
35-39	37.0	9.75	83	—	—	—
40-44	41.7	11.10	94	—	—	—
45-49	46.9	12.38	104	—	-	
50-54	51.9	13.73	126	—	—	
55-59	56.9	15.04	103	—	—	—
60-64	61.9	16.18	65	—	—	—
65-69	67.2	17.80	79	—	—	—
70-74	71.8	19.36	57	72.5	22.99	12
75-79	77.0	21.66	76	77.2	22.67	29
80-84	82.3	22.66	74	82.3	23.72	38
85-89	86.9	23.63	65	87.0	23.95	38
90-94	91.7	23.93	48	92.0	24.85	29
95-99	96.4	24.17	25	96.9	24.77	25
100-104	102.0	25.85	17	102.2	26.12	23
105-109	106.8	24.38	6	106.8	25.97	6
110-114	113.5	28.25	2	111.0	27.20	3

TABLE 2.—*Average back-calculated fork length in inches for 238 lake trout, Cayuga Lake, 1955 summer gill net samples*

Number of fish	Year class	Age group							
		I	II	III	IV	V	VI	VII	VIII
6	1954	4.77	—	—	—	—	—	—	—
50	1953	4.84	7.66	—	—	—	—	—	—
87	1952	4.64	7.49	10.69	—	—	—	—	—
31	1951	4.85	7.83	11.83	15.96	—	—	—	—
30	1950	4.63	7.57	11.33	15.59	19.12	—	—	—
24	1949	4.77	7.61	11.34	15.66	19.30	22.17	—	—
6	1948	4.68	7.27	10.62	14.58	18.57	21.88	23.95	—
4	1947	4.88	7.65	10.85	14.05	18.38	21.48	24.12	25.58
Class means	—	4.76	7.58	11.11	15.17	18.84	21.84	24.04	25.58

computed in the usual fashion, using logarithmic transformation of a regular exponential function, was as follows:

$$\log (L\text{—}2.0) = 0.10783 + 1.188665 \log S$$

where L = fork length in inches and S = scale radius in millimeters x 47 ½. Linearity accounts for 99.864 percent of regression variance (correlation coefficient squared). The smooth curve shown in Figure 2 was obtained by substituting scale radius measurements in the above equation. The intercept value (S = 0) was 2.11. The inflection above 22 inches in length was fitted by eye.

CONSTRUCTION OF A BODY-SCALE RULER

Construction of a body-scale ruler is described by Hile (1950). The body-scale ruler (made directly from a curve similar to Figure 2, but plotted on a large scale) differed from that described by Hile in that it was prepared in reverse. It was graduated in terms of body length but labeled in units of scale measurements. The ruler was then photographed and a print obtained of convenient length (about 8 inches) for the back-calculating device (Figure 2, B). This photographic step greatly facilitated the preparation of the body-scale ruler. The accuracy of the ruler was then checked against the original curve. Discrepancies ranged from 0 to ± 0.04, (one deviation of 0.09) with no indication of trend. It was concluded that photographic methods involved in the construction of the ruler had not introduced any systematic error. Special photographic papers, such as the Resistorapid used, minimize distortion due to shrinkage.

MECHANICS OF BACK CALCULATION

A back-calculating device suitable for a direct proportion body-scale relation was available (Schuck, 1949). Such a device ca be modified to accommodate any curvilinea relation described by a body-scale rule providing the ruler is graduated in bod length but labeled in units of scale measure ment. The ruler is taped into position alon the perpendicular line usually occupied b cardboard strips marked with scale measure ments, or projected scale image. Other step in back-calculation then proceed in conven tional fashion. The intercept value is sub tracted mechanically from the length scal by sliding this scale below the base line. Th proportion for any given specimen is se up by aligning the hairline of the swingin arm with values representing the scale radiu and the length of the fish at capture Measurements must be at the same magnifi cation at which the body-scale ruler wa prepared.

COMPARISON OF OBSERVED AND CALCULATED VALUES

Specimens obtained in the 1955 seaso were used for back calculation. Individua means of the several age groups and clas means are given in Table 2. A comparison o these calculated data with data obtained em pirically from fish collected in the middle o the growing season was made graphically a described below. Growth is conventionally illustrated as a smooth curve constructed by connecting the mean lengths at successive ages. This curve is a convenient comparative method of depicting growth, but is a marked departure from the actual sinuous type o curve describing the seasonal growth patter of many fishes. Empirical data showing the slow winter growth and more rapid spring or summer growth are exemplified by studies of Poulsen (1938) on cod. Data presented by Went and Frost (1942) on brown trout, by

llen (1941) on salmon parr and brown out, by Cooper (1953) on brook trout, by askell and Griffiths (1956) on hatchery ook trout, and by Kennedy (1954) on lake out also give a clear indication of this sea- nal change in growth rate.

The present problem was comparison of bserved growth data with a seasonal growth urve based on calculated data. If it is ssumed that the calculated length at an an- ulus is an indication of size at the end of e growing season and the beginning of next, the actual dates of the growing sea- n must be estimated so that the calculated ngths can be plotted with reasonable ac- racy.

These dates were determined from the sition of the current annulus in a series of ales taken April through August. The mount of new growth was expressed as a rcentage of the total scale radius, since is transformation reduced the variation due scale size. Means of these ratios, segregated y age groups, are shown in Figure 3.

Growth of the scales clearly did not begin til early April in age-groups IV and older. o early season data are available for younger age groups, but it is assumed that the same date approximated the beginning of the growing season for these fish also. The end of the growing season is not clearly indicated in this series of scales. Estimates were made by determining the ratio of a full season's scale growth for each age group. Average scale radii at each age were read from Figure 2, the increments determined, and these expressed as percentages of the total radius. The ratios corresponding to the appropriate age groups are indicated by the dotted horizontal lines in Figure 3. The point of intersection between this line and the extrapolation of the seasonal growth-ratio line is considered to approximate the end of the growing season. These points doubtless underestimate the length of this period because of the expected curvilinear nature of actual growth. For this reason, the growing seasons are arbitrarily considered to extend a month beyond the point of intersection.

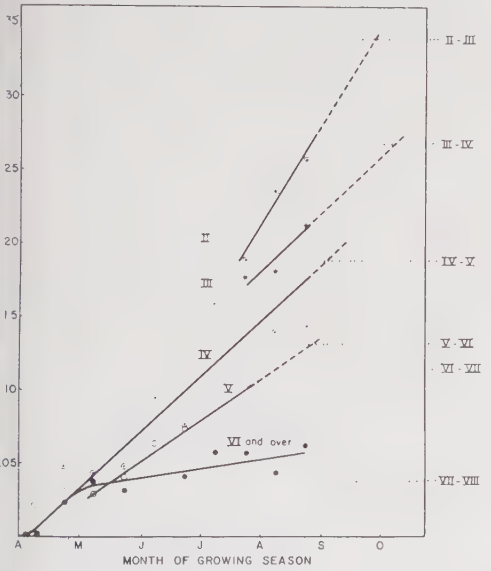

FIGURE 3.—Ratio of current scale growth to scale adius in lake trout taken April-August, Cayuga ake. Curves for each age group fitted by eye. Dotted nes, ratio for completed season's growth between ges indicated on right margin. Number of speci- ens: age II, 60; III, 88; IV, 150; V, 193; VI and wer, 160.

The relationships depicted in Figure 3 indicate longer annual periods of growth in age-groups II and III than those from older trout. This might be expected since lake trout in Cayuga Lake are not known to mature until age IV (some males). A relatively short period of growth is apparent for older trout of age VI and over.

Using somewhat similar methods, Kennedy (1954) estimated that the termination of active growth for the commercially exploitable segment of the population of lake trout in Great Slave Lake was in mid-September. Increments in length of recaptured tagged fish in South Bay, Lake Huron, indicated rapid growth through September (Fry, 1953). It appeared from the total season's increment that rapid growth may have continued beyond this date, although this point could only be determined by extrapolation.

In comparing calculated and observed lengths of Cayuga Lake trout, the growing season is assumed to extend from April through October for age-groups I - III (no mature fish), April through September for age-groups IV and V (partially maturing), and April through August for age VI and over (mostly mature). The same length value for any age group was plotted at the end of one growing season and at the beginning of the next (Figure 4). A line connecting the points at the beginning and end of the same growing season provides an estimate of fish length at any time within the growing season.

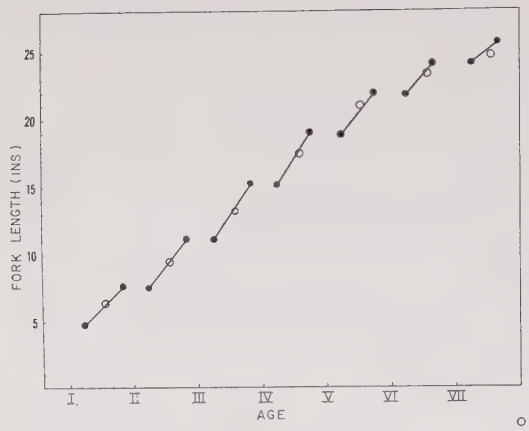

FIGURE 4.—Comparison of calculated and observed growth of 1947-54 year classes of lake trout, Cayuga Lake. Open circles, means of observed growth of midsummer samples. Solid circles, calculated mean lengths at beginning and end of growing season.

The slope of this line is the best available estimate of the actual rate of growth. This relationship is probably sigmoid in nature, but since empirical data are lacking, the straight line is used.

Observed growth data suitable for comparison with the calculated values were selected in the following way. Information similar to that in Table 2, but based on the observed growth in collections from 1949 to 1955, was obtained by Webster *et al.* (1959). From these data, mean observed lengths corresponding to the appropriate year class and age group of the calculated data were selected. For example, the appropriate observed figures involving the same year class for an age VIII+ fish in 1955 would be age VII in 1954, age VI in 1953, etc. Class means for these observations are also given in Table 3 and plotted in Figure 4 on a date, the last week in July, representing the approximate mid-point of the gill-net sampling period. Since summer sampling was quantitative, this date was reasonably consistent each year.

The agreement between the calculated and observed growth compared in this way is excellent. A maximum deviation of about 0.5 inch occurs at age VII. It is concluded that the method for back calculation used provides an accurate estimate of the size of lake trout at each annulus.

Reduction in variability in the calculated data is shown by the frequency distribution of age III fish (Figure 5). This result might be anticipated as observed growth data were collected over nearly 2 months of the active growing season, whereas calculated data refer only to the time of annulus formation. Calculated lengths also show a more normal dis-

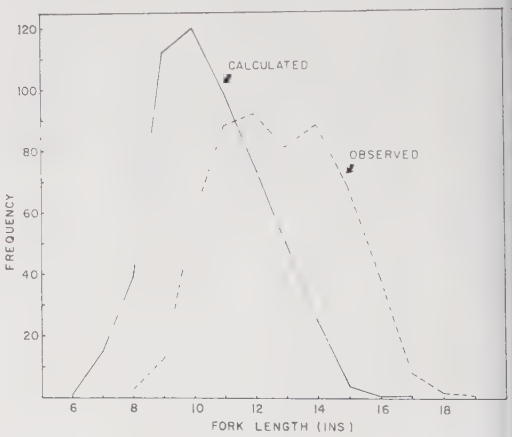

FIGURE 5.—Frequency distribution of calculated and observed length in 545 3-year-old lake trout, Cayuga Lake.

TABLE 3.—*Average observed fork length in inches for 1,380 lake trout, Cayuga Lake, summer gill-net samples, 1949-55*

[Each observed length corresponds with that calculated for the same year class and age in Table 2.]

Year class	Age group							
	I+	II+	III+	IV+	V+	VI+	VII+	VIII+
1954	5.95	—	—	—	—	—	—	—
1953	6.60	8.89	—	—	—	—	—	—
1952	6.40	9.63	12.05	—	—	—	—	—
1951	7.30	9.95	13.80	17.42	—	—	—	—
1950	5.80	8.88	12.85	16.93	20.41	—	—	—
1949	6.23	9.44	13.15	16.82	20.87	23.13	—	—
1948	6.80	9.75	13.67	18.14	20.28	23.57	24.62	—
1947	—	10.26	13.51	18.11	22.25	23.33	24.59	26.00
Class means	6.44	9.54	13.17	17.48	20.95	23.34	24.61	26.00
Total number of fish	21	310	575	232	129	75	31	7

ribution. The variance of the observed data as 3.973 as compared to 2.956 for the back-alculated data. Differences between the var-nces are significant at the 1 percent level:

$$F = \frac{3.937}{2.956} = 1.344$$

ith 545 degrees of freedom for both var-nces. Figure 1 indicates variance increases ith fish size so the reduction of variance ight be more evident in older age groups. he use of calculated data would increase the recision of critical growth comparisons.

ACKNOWLEDGMENTS

The authors are indebted to Dr. Douglas Robson, partment of Plant Breeding, Cornell University, o assisted with the curve fitting and suggested the eans of modifying a conventional proportional ack-calculating device to include any body-scale tio. Mr. Douglass Payne, Laboratory Technician, epared, in part, the accompanying figures. Scales ere mounted and read by Mr. Carl Parker, Dr. ilbur Hartman, and by the senior author. Measure-ents of new growth on the scale margins were ade by Mr. Bradford Brown.

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The Relative Effectiveness of Salmon Eggs and Earthworms as Bait for Trout in the Sturgeon River, Michigan

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ABSTRACT

The relative effectiveness of salmon eggs and large earthworms as bait for trout, and the efficiency of chumming with either lure, were tested by experimental fishing in the Sturgeon River (Cheboygan County), Michigan, on 35 different days during 1957 and 1958. Four anglers fished in pairs in any series of test days, using standardized terminal tackle under a systematic pattern of lure and method. Ten individuals fished 778 hours and caught 506 rainbow trout, 73 brown trout, and 12 brook trout. Logarithmic transformations were applied to the individual catch-per-hour data, followed by a factorial analysis of variance. Large (10-24 inches) rainbow trout in the summer of 1958 were caught 3.8 times faster on salmon eggs than on worms; smaller trout were caught 2 to 9 times faster on eggs than on worms; and chumming did not increase the efficiency of either lure for any size of fish. The differences noted between average total lengths of egg- and worm-caught trout were not statistically significant. Eggs caught a significantly larger fraction of small rainbow trout than did worms, but both lures took about the same proportion of larger rainbow trout. The estimated age distribution of rainbow trout caught is presented.

Among various natural baits used to capture rainbow trout in the Sturgeon River drainage (Cheboygan and Otsego counties) in recent years (prior to 1954), two of the more popular lures have been salmon eggs and large earthworms *(Lumbricus terrestris)*. Claims that salmon eggs were so effective in capturing trout, especially if egg chumming was employed, that they constituted a threat to the rainbow trout population led the Conservation Commission to ban their use on the Sturgeon River after April 20, 1954. The present study was designed to answer the question of whether salmon eggs are more effective than earthworms as bait in catching trout, and whether chumming increases the catch. The conclusions from this study are that salmon eggs are several times more effective than worms as bait, but that chumming with either salmon eggs or worms does not increase the catch.

METHODS AND EXPERIMENTAL DESIGN

Test fishing was done by two pairs of anglers (not always the same individuals) during the fall of 1957 and during the spring and summer of 1958 on 35 different days at 12 different sites on the Sturgeon River proper, and at the "walleye hole" off the mouth of the stream in Burt Lake. The experimental anglers used salmon eggs and worms alternately, and chummed during half of their fishing. Choice of bait and method of fishing (*i.e.*, chumming or not chumming) was systematized for precise analysis. Chumming was done by throwing 5 to 30 pieces of bait into the water at the site to be fished. The baits were fished on either a fly rod or spinning rod equipped with 6- or 8-pound test monofilament nylon line. Terminal tackle consisted of No. 8 or No. 10 short-shank gold hooks for egg fishing, and No. 6 long-shank Mustad hooks for worm fishing. One or more split shot were pinched on the line about 14 inches above the hook, depending on the current velocity at the site fished. Salmon eggs of a popular brand were used for egg fishing, and worms in lots of 100 to 500 were purchased as needed.

The total length of all fish caught was measured in inches, and most fish larger than 10 inches were scale-sampled for age determination. Except for approximately 20 hooking mortalities, all fish captured were released. A high percentage of the fish taken on salmon eggs were hooked lightly in the edge of the jaws because of the manner in which this lure was customarily fished. Field records were kept on 3- by 5-inch cards, one for each hour of angling. Records included the angler's name, date, time, lure, whether or not chumming was employed, and the species, number, and lengths of fish caught. Ten employees of the Fish Division including the

author took part in the experimental fishing. A majority of these men had prior experience in the use of worms as bait, but little or none in the use of salmon eggs. Any bias due to this factor of experience should have resulted in an increased catch with worms.

Four anglers, divided into two teams, always fished during the same time period. One team chummed while the other did not, and the team which chummed on a given day or half-day fished without chumming during the following period. One angler on each team used eggs while the other used worms; at the end of 1 hour they reversed baits; and at the end of 2 hours they exchanged fishing sites on the stream for a second 2 hours of fishing during which they again reversed baits at the end of 1 hour. At any one time, therefore, each of the four anglers was fishing under a different combination of lure and method, and over the span of two consecutive 4-hour test periods, or ½-day units, each combination of bait and angling method was used by each angler. The sampling design, shown in Table 1 as an analysis of variance, was a factorial experiment (Snedecor, 1956) with three factors, each considered to be a fixed effect. These factors were bait, angling method, and time block (two consecutive ½-days). The estimate of experimental error is based upon the duplicated measurements made at each trial. The best comparison, and the one of primary interest, was of bait (eggs *versus* worms) with each angler fishing each bait at each trial. The effect of chumming was tested on a somewhat different basis with each angler chumming on alternate trials. Such a comparison might be affected by any interactions of anglers with the various experimental effects.

TABLE 1.—*Experimental design of test fishing on the Sturgeon River, 1957 and 1958, showing distribution of bait and angling method among the anglers*

[E = eggs only, EC = eggs chummed, W = worms only, WC = worms chummed.]

Period	Angler	Hour of fishing during ½ day[1]			
		1st	2nd	3rd	4th
First ½ day	A	E	W	E	W
	B	W	E	W	E
	C	EC	WC	EC	WC
	D	WC	EC	WC	EC
Second ½ day	A	WC	EC	WC	EC
	B	EC	WC	EC	WC
	C	W	E	W	E
	D	E	W	E	W

[1]Angling was usually started between 8:00 a.m. and 8:30 a.m. and extended for a 4-hour period; angling in the afternoon began between 1:00 p.m. and 2:00 p.m. and was carried on until 5:00 p.m. or 6:00 p.m.

RESULTS OF ANGLING

In Table 2 the catch of all anglers is divided according to lure, method, and season, and the numbers of brook and brown trout of all sizes are combined. Fish other than trout (20 white suckers, 1 walleye, 1 creek chub, and 1 sculpin) caught during the three fishing periods are not included in the tabulations. Rainbow trout were classified as *lake-run*, or *other*, and the observed size ranges are shown. A rainbow trout was classified as a lake-run fish if it was 10.0 or more inches in length and silvery in color. The smallest silvery-colored fish taken at the river mouth was 10.0 inches long. Only 4 out of the 63 lake-run fish captured were less than 12 inches long, but 21 *other* rainbow trout between 10 and 12 inches in length were judged as *other* on the basis of the location of capture (near Wolverine) and lack of silvery coloration. The presence of planted legal-size rainbow trout, some of which exceeded 10 inches in length, negated the use of an arbitrary minimum length as a criterion for identifying lake-run fish.

A majority of the 11 lake-run rainbow trout taken during the fall of 1957 were caught in the walleye hole off the mouth of the Sturgeon River in Burt Lake. Relatively few lake-run fish were observed in any part of the Sturgeon River proper during the fall fishing in 1957. The experimental fishing in the river during early May of 1958 yielded only five lake-run fish. Warm weather during early March of 1958 apparently brought about an early run of spawning adults, and it is believed that many of these fish had returned to Burt Lake before the opening of the trout season. The summer fishing of 1958 provided the only large series of lake-run rainbow trout (47) taken in the stream.

In 330 hours of fishing in the fall of 1957, 122 rainbow, 25 brown, and 3 brook trout were caught. Slight deviations from the experimental pattern on 3 days, which were caused mainly by loss of tackle by individual anglers, resulted in slightly more hours of chumming (Table 2). In 81.5 to 84 hours of fishing with each lure and type of fishing, the catch of trout of all sizes was as follows: (1) salmon eggs only—76 rainbow, 4 brown;

TABLE 2.—*Summary of number of trout caught and hours of fishing, by season and method of angling, during test fishing with salmon eggs and worms, Sturgeon River and Burt Lake, 1957-1958*

Bait and fishing method	Species and hours fished	Size range (inches)	Year and season			
			1957, fall	1958, spring	1958, summer	Total[1]
Eggs only	Rainbow					
	Lake run	10.0–16.0	4	0	23	27 (7)
	Other	4.0–11.9	72	54	73	199
	Brown	—	4	8	0	12
	Brook	—	0	1	0	1
	Hours	—	81.5	48	64	193.5
Worms only	Rainbow					
	Lake run	14.1–17.5	1	0	1	2 (2)
	Other	4.0–11.9	10	27	15	52
	Brown	—	5	4	2	11
	Brook	—	2	3	0	5
	Hours	—	81.5	48	64	193.5
Eggs, chummed	Rainbow					
	Lake run	13.0–23.7	6	2	17	25 (10)
	Other	4.0–11.9	23	36	88	147
	Brown	—	13	20	5	38
	Brook	—	0	2	0	2
	Hours	—	84	48	64	196
Worms, chummed	Rainbow					
	Lake run	11.0–16.8	0	3	6	9 (1)
	Other	6.0–9.9	6	16	23	45
	Brown	—	3	8	1	12
	Brook	—	1	3	0	4
	Hours	—	83	48	64	195
Total	Rainbow					
	Lake run	10.0–23.7	11	5	47	63 (20)
	Other	4.0–11.9	111	133	199	443
	Brown	—	25	40	8	73
	Brook	—	3	9	0	12
	Hours	—	330	192	256	778

[1]Numbers in parentheses indicate lake-run fish hooked and played long enough for positive identification, but not landed. These fish are not included in any other tabulations.

(2) worms only—11 rainbow, 5 brown, 2 brook; (3) salmon eggs chummed—29 rainbow, 13 brown; and (4) worms chummed—6 rainbow, 3 brown, 1 brook. The catch of lake-run rainbow trout was 4 on eggs only, 1 on worms only, and 6 on salmon eggs chummed, or a total of 11.

During the spring of 1958, a total of 192 hours of angling yielded 138 rainbow, 40 brown, and 9 brook trout. In 48 hours of fishing with each combination of bait and method, the trout catch was as follows: (1) salmon eggs only—54 rainbow, 8 brown, 1 brook; (2) worms only—27 rainbow, 4 brown, 3 brook; (3) salmon eggs chummed—38 rainbow, 20 brown, 2 brook; and (4) worms chummed—19 rainbow, 8 brown, 3 brook. Only five lake-run rainbow trout were caught; two on salmon eggs chummed, and three on worms chummed.

During the summer of 1958, a total of 256 hours of fishing took 246 rainbow and 8 brown trout. In 64 hours of fishing with each combination of bait and method, the catch of trout was distributed as follows: (1) salmon eggs only—96 rainbow; (2) worms only—16 rainbow, 2 brown; (3) salmon eggs chummed—105 rainbow, 5 brown; and (4) worms chummed—29 rainbow, 1 brown.

For trout of all sizes (Table 2) eggs were about 3 times as effective as worms, and chumming was no more effective than not chumming. For lake-run rainbow trout, eggs were about 5 times as effective as worms, and chumming was only slightly more effective than not chumming. Whether the differences are statistically significant can be determined only by relating the differences to the variation in catch by individual anglers during various periods of test fishing. To allow for possible differences in angler skill and in fishing quality from day to day, the analysis of variance is the most appropriate test. For this analysis the catch per hour was computed for each angler's fishing with one bait during a 2-hour period. A logarithmic transformation of the observed catch-per-hour data was used because preliminary analysis of the untransformed data on catch per hour showed a relationship between mean and variance, as well as a number of high interaction terms.

The pertinent summaries of analysis of variance are shown in Tables 3 and 4 for the following sets of data: (1) lake-run rainbow trout, summer, 1958, sorted for individual angling records; (2) lake-run rainbow trout, summer, 1958; (3) all trout, exclusive of lake-run fish, fall, 1957; (4) all trout, exclusive of lake-run fish, spring, 1958; and (5) all trout, exclusive of lake-run fish, summer, 1958. The last three analyses were included to provide information on the efficiency of the experimental baits and fishing methods on the smaller fish in the Sturgeon River trout population. The empirical data for the above-listed analyses consist of the hours of angling and numbers and species of trout taken by the individual anglers.

TABLE 3.—*Summary of analysis of variance on differences among anglers in fishing for lake-run rainbow trout, summer, 1958, Sturgeon River, Cheboygan County*[1]

[Logarithmic transformation of catch per hour per 2-hour period—Log ([Catch/hr x 100] + 1)]

Source of variability	Degrees of freedom	Mean square	F value
Total	127	—	—
Bait	1	11.1392	21.45**
Method	1	0.2450	0.47
Anglers	3	0.3580	0.69
Time blocks	7	0.6352	1.22
Bait x method	1	0.1696	0.33
Bait x angler	3	0.4112	0.79
Bait x time block	7	0.5964	1.15
Method x angler	3	0.1641	0.32
Method x time block	7	0.5228	1.01
Angler x time block	21	0.6346	1.22
Error term	73	0.5193	—

[1]Empirical data on file at the Hunt Creek Trout Research Station of the Institute for Fisheries Research.
**Indicates a significant difference at the 1 percent level.

To examine the question of whether or not any interaction existed between anglers and the various experimental effects, a separate analysis treating anglers as a fixed effect was made for the data concerning lake-run fish only (Table 3). In this tabulation it was necessary to combine results from an angler and his substitute, where one man was not able to finish a series of trials. The term *time block* refers to a pair of consecutive ½-day fishing trials during which each angler fished with all baits and methods. This analysis showed no significant interaction of anglers with any factor. Furthermore, there is no evidence of difference in effectiveness among the experimental anglers.

ANALYSIS OF THE ANGLING RESULTS

Results from the test fishing have been examined in several ways. The question of greatest importance, the relative effectiveness of salmon eggs and worms as bait for lake-run rainbow trout, could be tested only with data from the summer of 1958, when there were enough lake-run fish captured to permit an analysis (Table 3). Captures of all other trout, excluding lake-run rainbows, were analyzed in a similar way (Table 4). Size and age of fish caught have been examined in lesser detail.

The analyses of the angling results during the summer season on lake-run rainbow trout show a highly significant difference between baits, favoring salmon eggs, with no other significant effects or interactions. Salmon eggs were estimated to be 3.8 times more effective

TABLE 4.—*Summary of analyses of variance of catch of trout in test fishing, Sturgeon River and Burt Lake, Cheboygan County, Michigan*[1]

[Logarithmic transformation of catch per hour per 2-hour period—Log ([Catch/hr x 100] + 1)]

Source of variability	Lake-run rainbows only, summer, 1958		All trout, excluding lake-run rainbows					
			Fall, 1957		Spring, 1958		Summer, 1958	
	d.f.	m.s.	d.f.	m.s.	d.f.	m.s.	d.f.	m.s.
Bait	1	11.14**	1	7.00**	1	15.75**	1	30.40**
Method	1	0.24	1	0.94	1	0.00	1	0.00
½ days	15	0.56	20	3.04**	11	3.70**	15	3.68**
Bait x method	1	0.17	1	0.00	1	0.00	1	0.08
Bait x ½ days	15	0.64	20	0.77	11	1.18*	15	0.92**
Method x ½ days	15	0.69	20	0.68	11	0.80	15	0.67
Bait x method x ½ days	15	0.37	20	0.44	11	0.36	15	0.26
Error term	64	0.51	84	0.47	48	0.56	64	0.37
Total	127	—	167	—	95	—	127	—

[1]Empirical data on file at the Hunt Creek Trout Research Station of the Institute for Fisheries Research.
*Indicates a significant difference at the 5 percent level.
**Indicates a significant difference at the 1 percent level.

TABLE 5.—*Mean catch of trout per hour per 2-hour period by experimental anglers with eggs and with worms, with and without chumming (expressed in logarithmic units, with equivalent ratio of catch with eggs to catch with worms)*

Experimental series	Mean catch in log units[1]				Equivalent ratio eggs/worms[2]
	Eggs	Worms	Eggs chum	Worms chum	
Lake-run rainbow trout only, summer, 1958	0.716 (±0.126)	0.053	0.731	0.214	3.8 (2.2–7.0)
All other trout					
Fall, 1957	0.827 (±0.106)	0.415	0.673	0.269	2.6 (1.6–4.2)
Spring, 1958	1.572 (±0.152)	0.770	1.578	0.760	6.4 (3.2–13.0)
Summer, 1958	1.606 (±0.108)	0.683	1.645	0.622	9.3 (5.6–15.2)

[1]The standard errors (in parentheses) are based upon pooled variance and are the same for each mean within the same series.
[2]95 percent confidence limits shown in parentheses.

than worms in catching lake-run fish (Table 5). The catch of all other trout, excluding lake-run rainbows, in all three seasonal series showed superiority of salmon eggs over worms (Table 4). During the course of the testing the differences between baits increased successively in the series. Fishing success also increased, while success with worms was highest in the spring trials (Table 4). The skill of the investigators in the use of salmon eggs may have increased with experience, or there may have been a seasonal effect.

The analyses of variance for all trout, excluding lake-run rainbows, show a highly significant difference among ½-days for all three seasons. Since this difference means simply that fishing was measurably better on some ½-days (and at some places) than on others, the only unexpected result was that success in the catch of lake-run rainbow trout did not differ significantly among ½-days.

The interaction of bait with ½-days was significant in the spring and summer and indicated that the differences between baits operated at different levels of effectiveness on different days. On only one of the 28 half-days did the catch on worms exceed that made on salmon eggs. This interaction suggests a varying degree of superiority of eggs from one ½-day to another rather than a shift in superiority from one to the other bait.

In summary, the angling results for lake-run rainbow trout were relatively poor during the fall of 1957 and the spring of 1958 apparently because few lake-run fish were in the Sturgeon River at the time. Because there were few captures in these seasons, analyses of variance on data pertaining to the lake-run fish were not attempted. The 16 large fish caught during the fall of 1957 and the spring of 1958 were distributed as follows among the different fishing baits and methods: nine by salmon eggs chummed, four by salmon eggs only, two by worms chummed, and one by worms only. The fishing over the summer run yielded 47 lake-run rainbow trout and showed through analysis of variance that salmon eggs were 3.8 times more efficient than worms as bait for lake-run rainbow trout in the Sturgeon River. Similar analyses also showed that salmon eggs took a significantly larger number of smaller trout than the same amount of fishing with worms. Chumming did not increase the efficiency of the bait for either lake-run or other trout. The period fished within a season (or possibly the stream area) appeared to have some influence on the catch. Of 83 lake-run rainbow trout hooked in all three series of trials, 63 (75.9 percent) were brought to hand. Of the 20 fish lost after hooking, most escaped by throwing the hook or tearing off. Less than five broke the terminal tackle.

SIZE OF FISH TAKEN BY THE VARIOUS BAITS AND ANGLING METHODS

The numbers of trout, size range in inches, average total length and its standard error, and catch on two types of bait during the three seasons are given in Table 6. Rainbow trout caught on salmon eggs had an average total length of 8.6 inches; and those caught on worms, 9.0 inches. The standard *t* test did not indicate, however, that this difference in average length was significant. The percentage size-frequency distribution of rainbow

ABLE 6.—*Number and lengths of trout taken during the experimental fishing, Sturgeon River, 1957 and 1958*

Species of trout	Lure and method	Number of fish	Length in inches		
			Range	Average	Standard error
inbow	Eggs only	226	4.4–15.5	8.2	0.16
	Worms only	54	5.3–17.5	8.2	0.29
	Eggs chum	172	4.5–23.7	9.1	0.25
	Worms chum	54	6.0–20.5	9.9	0.40
	Total, eggs	398	4.4–23.7	8.6	0.14
	Total, worms	108	5.3–20.5	9.0	0.26
own	Eggs only	12	6.5–14.5	9.7	0.86
	Worms only	11	6.9–14.1	9.7	0.66
	Eggs chum	38	6.5–24.0	9.6	0.48
	Worms chum	12	7.0–14.0	9.8	0.68
	Total, eggs	50	6.5–24.0	9.6	0.41
	Total, worms	23	6.9–14.1	9.8	0.46
ok	Eggs only	1	8.8	8.8	0.00
	Worms only	5	7.2–12.3	8.6	0.93
	Eggs chum	2	6.9–7.0	7.0	0.07
	Worms chum	4	6.3–7.8	6.8	0.36
	Total, eggs	3	6.9–8.8	7.6	0.62
	Total, worms	9	6.3–12.3	7.9	0.39

out caught on salmon eggs and worms is iven in Table 7. These data indicate that bout 24 percent of the fish caught on salmon gs and 15 percent on worms were smaller an 7.0 inches. Chi-square tests were applied the size-frequency records, after the total tch with each bait was divided into three ngth categories (4.0-6.9 inches, 7.0-9.9 ches, and larger than 9.9 inches). The test r heterogeneity showed that there were ghly significant differences (Chi-square = 15.75, 6 degrees of freedom, $p<2$ percent), most of which were identified by testing chumming *versus* no chumming for fish smaller than 7.0 inches as compared to those 7.0 inches and larger (Chi-square value of 12.64; p is less than 0.1 percent with one degree of freedom). Less than half as many fish under 7.0 inches in length were taken with chumming as were caught without chumming, whereas bait or method had no significant effect on the catch of rainbow trout in the other two length groups. A comparison of the over-all effect of salmon eggs and worms revealed no significant difference in size of trout caught.

ABLE 7.—*Size-frequency distribution of rainbow trout caught by experimental fishing, Sturgeon River, 1957 and 1958*

Bait, angling method, and season	Length (inches)			Totals
	4.0-6.9	7.0-9.9	10.0-23.7	
ggs only				
Fall	28	42	6	76
Spring	18	32	4	54
Summer	21	52	23	96
Total	67	126	33	226
orms only				
Fall	1	6	4	11
Spring	11	14	2	27
Summer	—	15	1	16
Total	12	35	7	54
ggs chum				
Fall	10	11	8	29
Spring	8	23	7	38
Summer	11	76	18	105
Total	29	110	33	172
orms chum				
Fall	—	4	2	6
Spring	2	14	3	19
Summer	2	21	6	29
Total	4	39	11	54
otal all eggs	96	236	66	398
ercentage	24.1	59.3	16.6	100.0
otal all worms	16	74	18	108
ercentage	14.8	68.5	16.7	100.0

AGE DISTRIBUTION OF THE TROUT CAPTURED

Scale samples were taken from 242 rainbow trout, 71 brown trout, and 13 brook trout. Several of the larger brown trout and brook trout were caught by personal angling or picked up dead along the stream, but all rainbow trout were caught during the experimental angling described above. Among rainbow trout, age-groups O through VII were found; among brown trout (including the extra samples) age-groups I through VIII were noted; and among the few brook trout collected, only age-groups I through III were present.

The estimated age distribution (Table 8) of the total catch of rainbow trout by experimental fishing was determined by listing the scale samples by inch-groups and age for each season and determining what percentage

of the particular inch-group consisted of fish in various age groups. These percentages were then applied to the catch data for eggs and worms separately. Only in the fall season were any of the faster growing young-of-the-year rainbow trout subjected to hooking, and then mainly when eggs were used as bait. The probable reason for this result is related to the size of the lure in comparison to the length range of this age group. In the fall and summer fishing, yearlings (age-group I) were most commonly observed among rainbow trout caught with either eggs or worms. In the spring fishing, however, age-groups II and III were more numerous. Regardless of the season of fishing or the lure used, the three youngest age groups contributed approximately 90 percent of the fish hooked.

RELATIONSHIP OF LURE RESTRICTION TO REPRODUCTION OF RAINBOW TROUT IN THE STURGEON RIVER

The restriction against the use of salmon eggs has been in effect since April 20, 1954, on the Sturgeon River, and since April 20, 1956, on Burt Lake and the West Branch of the Sturgeon. No assessment of the effect of the salmon-egg restriction on natural reproduction of rainbow trout in the Sturgeon River is possible. No data on the numbers of pre-1954 spawning adults or of the average annual crop of fingerlings resulting from their spawning are available. Results of direct-current shocking for the years 1955, 1957, and 1958,[1] indicated that there was natural reproduction in the West Branch of the Sturgeon River in each of those years. Young-of-the-year rainbow trout were collected with alternating-current electrofishing gear at 17 of 23 sites sampled in the main Sturgeon River in August, 1958.[2] Native rainbow trout probably were also present at some of the other sites (the efficiency of the gear was rated poor at all shocking stations where young rainbow were not captured). The most that can be stated with certainty, therefore, is that natural reproduction continues in the Sturgeon River drainage at the present time. Whether it is on a higher or lower level than prior to 1954 cannot be determined from the facts at hand.

[1]Records provided by Dr. Robert C. Ball, Michigan State University, East Lansing, Michigan.

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[2]Data furnished by Roger Wicklund, Lake and Stream Improvement Section, Fish Division, Michigan Department of Conservation.

Table 8.—*Estimated age distribution of the total catch of rainbow trout taken by experimental fishing, Sturgeon River, 1957 and 1958*

Bait	Season	Estimated numbers of fish in age group								Total
		0	I	II	III	IV	V	VI	VII	
Egg	Fall	32	37	26	6	3	1	—	—	105
	Spring	—	19	36	35	1	—	—	1	92
	Summer	—	121	47	32	1	—	—	—	201
Worm	Fall	2	7	4	4	—	—	—	—	17
	Spring	—	11	13	21	—	—	1	—	46
	Summer	—	24	12	9	—	—	—	—	45
Total	Fall	34	44	30	10	3	1	—	—	122
	Spring	—	30	49	56	1	—	1	1	138
	Summer	—	145	59	41	1	—	—	—	246

The Development of Population Estimate Procedures in Small Trout Lakes[1]

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ABSTRACT

The development of suitable procedures of mark-and-recapture population estimation was undertaken on two small trout lakes. Effort was primarily applied toward evaluation of the assumption of equal vulnerability between marked and unmarked fish. Using traps and angling, four basic procedures were employed and the resulting estimates compared. Estimates obtained by *angling and recapture by angling* procedures were judged too high, apparently because marked fish had acquired a hook resistance. Estimates from a *trap and recapture by trap* procedure were too low when hoop nets were employed, but when hardware cloth traps were used the estimates were too high. Estimates obtained by procedures which involved making the recaptures by a different method, *trap and recapture by angling* and *angling and recapture by trap*, were considered best since they were compatible with known numbers present and numbers previously planted and agreed well with each other.

INTRODUCTION

At the Pigeon River Trout Research Station, Vanderbilt, Michigan, the evaluation of various experimental management programs employing a complete, permit-type creel census has been undertaken. Included among these programs are several involving small trout lakes which, in recent years, have received annual plantings of young-of-the-year brook trout. Although data obtained from the creel census, such as total catch, fishing pressure, and catch per unit effort, are indispensable for a thorough evaluation of experimental management, in some instances it was also desired to obtain information on population size. More specifically, it was desired to determine the numbers of each year class (identifiable by a distinguishing fin-clip mark made at the time of planting) which were present immediately before the opening, and after the close, of the trout fishing season. With these data, in addition to total anglers' catch obtained from the creel census, the fate of each year class could be ascertained. Starting with a known number at time of planting (autumn), mortality during the first winter in the lake, angling and natural mortality during the first summer, mortality during the second winter, and so on, could be determined until the entire year class had disappeared.

Since estimates that were both accurate (lack of systematic error) and precise (small sampling error) were necessary for this purpose, considerable effort was applied to the development of a desirable procedure. An intensive attack on the problem was made possible by the small size of the lakes (10 acres and less), which permitted intensive sampling, and the very high degree of activity of the brook trout and consequent ease of capture at the two times of year at which population measurements were desired.

Since intensive effort was applied under favorable circumstances, confidence intervals were usually narrow enough so that systematic errors could be demonstrated. This report presents descriptions of these systematic errors so that they may be recognized in other population estimations where similar favorable circumstances may not be present or where sampling, for practical reasons, cannot be done as intensively. No attempt at evaluation of the experimental management itself, nor many adjunctive data which are applicable only to the Pigeon River lakes are included here.

NECESSARY ASSUMPTIONS

Ricker (1958) has discussed in detail the several assumptions which must be made in a mark-and-recapture procedure of population estimation. The following assumptions may be made in the case of the Pigeon River lakes with considerable assurance: (1) there is no recruitment problem since the trout popula-

[1]Contribution from the Institute for Fisheries Research, Michigan Department of Conservation.

tions are maintained only by plantings of marked fish in known numbers and sizes; (2) marked fish (fin-clipped) would not lose their mark over the short period of time involved; (3) non-random distribution of the fish, or sampling that was not proportional to fish density, would be unlikely because there was a high degree of fish activity and an intensive fishing effort; and (4) recognition of all marks would be likely since only technical personnel were involved in the study.

Another assumption, which could not be accepted without considerable suspicion, however, is that the marked fish are as vulnerable to recapture as are the unmarked ones. This assumption means, among other things, that the method of original capture and marking must not impose any physical effects or changes in behavior in the fish which change their vulnerability, and also that there are no initial individual differences in susceptibility to the method of capture for which corrections cannot be made. As Ricker points out, this is an assumption which is extremely difficult to evaluate. Unfortunately, the systematic errors which may be in the estimate as a result of the assumption not holding true may be considerable. The scarcity of tests of this assumption in the fishery literature appears to bear out the suggested difficulty.

It has been suggested frequently that a means of overcoming some of the possible systematic errors involved in differential vulnerability between the marked and unmarked fish, particularly when passive methods of capture are used, is to obtain the recapture samples by a method of capture different from the method of original capture in order to avoid sampling bias due to effects of the original capture. Several instances have been reported where estimates obtained by such a "mixed" procedure (*i.e.*, capture by one method and recapture by another) have been compared to estimates obtained by a "pure" procedure (*i.e.*, capture and recapture by the same method) (Ricker, 1942; Lawrence, 1952; Cooper, 1952; Cooper and Schafer, 1954; Carlander and Moorman, 1956). In most of these instances the estimates have differed, sometimes considerably, but there was little to indicate which was the better estimate or to identify possible systematic errors. Lawrence (1952) compared an estimate of a bluegill population in an Iowa farm pond made by a seine-and-recapture-by-trap procedure with an estimate made by traps only and found that the estimate by the former was about twice that by the latter. The traps were baited, however, so the trapped fish may have been attracted to them for another meal. Lagler and Ricker (1942) reported that marked crappies which had been trapped in fyke nets apparently appeared in recapture samples in a higher proportion than they were present in the lake. Several other workers have reported estimates obtained by trapping which have been too low when compared to the return from subsequent poisoning. On the other hand, Loeb (1958) reported pure estimates, which he considered acceptable, using seining alone and electrofishing alone. He points out, however, that a method such as electrofishing does not depend on fish behavior, as does trapping, and a procedure involving different methods of capture would not be as necessary.

The final necessary assumption, that there is equal mortality between the marked and unmarked fish, could not be made with assurance at the start of the field operations in these lakes. When significant differences are noted among two or more estimates of the same population, however, as was the case in the present study, and the method of original capture is the same in all procedures, the reason for the differences must be assigned to factors other than differential mortality caused by the method of original capture and marking.

In the present study, by comparing mixed and pure estimates, and by using other data available, some tests of the assumption of equal vulnerability were possible.

METHODS OF CAPTURE AND ESTIMATION

The two methods of capture employed were traps and angling, both of which are passive and depend upon behavior of the fish. By sampling with both methods and marking the fish differently for each method, four independent estimates of each population in question were obtained for comparison. Two of these estimations are by pure procedures: (1) *angling and recapture by angling*, and (2) *trap and recapture by trap*. The other two are mixed procedures: (3) *angling and recapture by trap*, and (4) *trap and recapture by angling*.

Ford Lake (about 10 acres) and Hemlock Lake (6 acres) were used in the present

udy. Ford Lake had received annual plant-gs of 5,850 brook trout (age-group O), hile Hemlock Lake had received annual lantings of 3,000. All plantings were made n the autumn. A few trout entered the ang-rs' catch as I-annulus fish during the sum-ner following plantings, but the great major-y of those taken were caught during the irst few weeks of the trout season about 1½ ears after planting. Few trout were taken y anglers after their second summer in the ake. The study was begun in the autumn of 956 when the 1955 year class, approximately ½ years old, was predominant. Other de-ails of methods, since they varied according lake and to the stage of the program's rogress, will be given in later sections.

POPULATION ESTIMATES

Population estimates made in the autumn f 1956 of the 1955 year class (including a ery few survivors of the 1954 and 1953 year lasses) are presented in Table 1 for Hem-ock and Ford lakes. The method of Schu-acher and Eschmeyer (1943) was employed t this time, and 95 percent confidence limits ere obtained by the method discussed by icker (1958, pp. 102-103) using formulas iven by DeLury (1958) and Schumacher and schmeyer (1943). Field operations were onducted in Hemlock Lake from October 6 to October 30 and in Ford Lake from November 5 to November 20; the traps were ifted, moved, and reset during the morning, nd angling was conducted by the research tation staff during the afternoon using artificial flies. The traps used were hoop nets with wings. The top corner of the caudal fin was clipped on trap-caught fish and the lower corner on angler-caught fish. All marked fish were released near shore, but not in the immediate vicinity of a trap.

TABLE 1.—*Population estimates of the 1955 year class in Hemlock and Ford lakes, autumn 1956, using various procedures*

Procedure	Population estimate	95 percent confidence limits	
emlock Lake			
Angling and recapture by angling	1,044	893	1,256
Trap and recapture by trap	471	439	508
Trap and recapture by trap, by size groups	482	—	—
Trap and recapture by angling	528	466	609
Angling and recapture by trap	539	496	591
Angling and recapture by trap, *M* corrected	524	476	584
ord Lake			
Angling and recapture by angling	833	492	2,717
Angling and recapture by angling, in two periods	633	541	762
Trap and recapture by trap	411	389	436
Trap and recapture by angling	432	395	476
Angling and recapture by trap	500	463	544
Angling and recapture by trap, *M* constant	465	428	509

Estimates of the 1956 year class made in the spring of 1957 are presented in Table 2. For these estimates the period between the time that the lakes were first ice-free and the opening of the trout season was very short. Field operations before the trout season opened consisted of trapping only, using the Schumacher-Eschmeyer method. Trapping was conducted during the periods from April 16 to April 21 in Ford Lake and from April 22 to April 25 in Hemlock Lake. The traps used at this time were constructed of ½-inch (or less) mesh hardware cloth, presumably similar to those employed by Lawrence (1952). They were 3 feet long and triangular in cross-section, with each side being 2 feet in length. A funnel was constructed into one end while the other end was closed except for a small hinged door for removing the catch. In Ford Lake the mark used was the removal of an entire pectoral fin (a permanent mark was desired so that an additional estimate could be obtained at a later time for comparison). In Hemlock Lake half the fish were marked by removal of a pectoral fin and half by clipping a corner of the caudal fin. All marked fish were released at a central point, although the distance from this release point to the nearest trap was not much different than from release points near shore. Recapture samples for the *trap and recapture by angling* estimate were obtained from angling done by the research station staff after the opening of the trout season. This estimate was made by the direct-proportion, or Petersen, method, and 95 percent confidence limits were obtained from tables of binomial confidence limits given by Mainland, Herrera, and Sutcliffe (1956).

ANGLING AND RECAPTURE BY ANGLING ESTIMATES

The estimates obtained by this procedure of the 1955 year class in both Hemlock and Ford lakes, 1,044 and 833 respectively, were suspected of being too high, since in both lakes these estimates lay considerably above estimates obtained by all other procedures.

TABLE 2.—*Population estimates of the 1956 year class in Ford and Hemlock lakes, spring 1957, using various procedures*

Procedure	Population estimate	95 percent confidence limits	
Ford Lake			
Trap and recapture by trap	5,742	4,803	7,138
Trap and recapture by trap, last day's sample	5,041	3,849	6,689
Trap and recapture by angling	4,410	3,840	5,200
Autumn 1957, check estimate	4,624	4,052	5,333
Hemlock Lake			
Trap and recapture by trap, pectoral clip	3,750	2,055	21,394
Trap and recapture by trap, caudal clip	3,711	2,207	11,659
Trap and recapture by trap, pectoral clip, last day's sample	3,406	2,577	4,425
Trap and recapture by trap, caudal clip, last day's sample	3,206	2,439	4,098
Trap and recapture by angling	2,591	2,449	2,799
Autumn 1957, check estimate	2,997	2,408	4,034

One possible reason for the estimates being too high was mortality among the angler-caught trout due to fatal hooking. All fish hooked badly, or where bleeding occurred, were held in a live cage in the lake for 24 hours, deaths were recorded, and appropriate corrections were made in the computations. Approximately 1 percent mortality was observed. The fact that the *angling and recapture by trap* estimates did not appear too high confuted the postulate of significant differential mortality.

Another possible explanation for the systematic error was that the trout which had once been caught by the angler's hook acquired a "hook resistance" and subsequently did not appear in the recapture samples in as high a proportion as they were present in the lake. Furthermore, it was observed that by the time that about 40 to 50 percent of the population had been caught and marked, catch per unit effort had decreased greatly. This decrease was probably due to another significant portion of the population acquiring a certain degree of hook resistance by being hooked and lost, a result which happened about as frequently as the hooking and landing of a fish.

In Ford Lake the hook-resistance postulate was evaluated experimentally by stopping angling after 5 days, permitting the trout to "rest" for a period of 10 days, and then angling again for another period using a different mark. The samples obtained during the second period of angling were then used for the estimation. The result was an estimate of 633, which was a reduction from the estimate of 833 for all angling. This procedure is listed in Table 1 as *Angling and recapture by angling, in two periods.* Apparently during the rest period the marked trout lost a certain amount, but not all, of their hook resistance, and consequently a lower estimate resulted.

It was concluded that the *angling and recapture by angling* procedure was not valid because there was a differential vulnerability between marked and unmarked fish due probably to a hook resistance displayed by the marked fish. It should be emphasized, however, that the hook resistance apparently is lost after some as yet unknown period of time. Perhaps valid estimates could be obtained by this procedure if sufficient time were allowed to elapse between periods of sampling, provided that the mark used was retained over the period of time involved.

TRAP AND RECAPTURE BY TRAP ESTIMATES AUTUMN 1956

In the autumn of 1956 the *trap and recapture by trap* estimates were too low in both lakes (Table 1). As evidence to support this conclusion, the estimates may be compared to the known minimum number present, which was the total number of original captures made with both traps and angling. In Hemlock Lake the minimum number was 515, while the estimate was 471, and the upper 95 percent confidence limit, 508, was also lower than the known minimum number. In Ford Lake the known minimum number, 422, although falling within the 95 percent confidence interval, was again higher than the estimate of 411. Furthermore, it would be expected that the true population size would be somewhat larger than the known minimum number, since it was highly unlikely that all of the fish had been captured. Obviously some systematic error was present in this procedure and produced a low estimate.

Several reasons are suggested to explain why the *trap and recapture by trap* estimates were too low in the autumn of 1956. The first of these is that the traps permitted some escapement of smaller sized fish, and consequently the procedure estimated only a portion of the population. That some escapement occurred was known to be true, since small fish were sometimes gilled in the mesh

of the traps and some were observed to escape. The estimate of the portion available to both methods of capture made by the *trap and recapture by trap* procedure, however, appeared to be lower than it should have been, when it was considered that the basis for judging the estimates was a comparison with the known minimum number captured by both methods, and that the size ranges and means of total captures by both methods were very similar (Table 3). *T*-tests indicated no significant difference (above 80 percent level) in either lake between the means for angling and trapping. It is therefore apparent that some other source of systematic error should be sought to explain why the estimates were less than the known minimum number.

One possible source of this error may have been in the location of the release point of the fish, which was near shore, approximately midway between two adjacent traps. This source of error remains a possibility, but it is probably not the principal cause of the error because (1) the release of angler-caught fish was also near shore, and the *angling and recapture by trap* estimates were higher, and (2) the lakes were small and the distances that the fish would have to travel back to the traps, whether a central release point or release points near shore were used, were not much different.

Cooper (1952) has suggested the possibility that estimates based on trapping may be too low because there is a failure of the "effective fields" of the traps to overlap completely. It is highly unlikely that this factor would be important in Ford and Hemlock lakes, however, in view of the intensity of the trapping relative to the size of the lakes and also in view of the very high degree of activity of the fish.

It is also possible that systematic errors were introduced by combining all sizes of fish, and these errors tend to produce an underestimate (Cooper and Lagler, 1956). To test this possibility, estimates in Hemlock Lake were computed for separate size classifications, using the following categories: (1) 6.0 to 7.9 inches in total length, (2) 8.0 to 8.9, and (3) 9.0 and longer. The summed estimate, 482, is given in Table 1 for the *trap and recapture by trap, by size groups* procedure. When this is compared to the combined estimate, 471, and to the known minimum number, 515, it appears that combining the sizes was not the factor causing the estimate to be too low. Actually, a large error due to combining sizes would probably not be expected, since the size range was narrow and most fish lay between 7.0 and 8.9 inches in length (Table 3).

Finally, the explanation which was tentatively accepted as most probable was that there was a variation in trap susceptibility among the fish in the lake when the hoop-net type of trap was used. Some individuals may have been more susceptible to trapping than others. Their repeated capture in the traps at a higher rate than others would result in a proportion of marked fish in the trap samples that was higher than the proportion of marked fish in the lake. It was concluded that the *trap and recapture by trap* procedure was not valid when used with hoop-net traps, because it produced estimates which were too low.

TRAP AND RECAPTURE BY TRAP ESTIMATES, SPRING 1957

In the spring of 1957, the *trap and recapture by trap* estimates of the 1956 year class (Table 2) were judged too high in both lakes. This conclusion was supported by the fact that, in both lakes, the estimates started at levels well above the numbers planted the previous autumn, then decreased progressively to level out at the figures presented in Table 2. In Hemlock Lake the final estimates of over 3,700 were considerably higher than the 3,000 planted during the previous autumn.

Several sources of systematic error are suggested. First, a central release point was used, but for reasons discussed in the previous

TABLE 3.—*Number of total captures made by angling and traps in Hemlock and Ford lakes during the autumn of 1956*

Total length (inches)	Hemlock Lake		Ford Lake	
	Angling	Traps	Angling	Traps
6.0 - 6.4	0	3	1	0
6.5 - 6.9	7	23	0	0
7.0 - 7.4	70	127	6	39
7.5 - 7.9	99	216	50	121
8.0 - 8.4	125	244	98	250
8.5 - 8.9	69	146	95	212
9.0 - 9.4	22	37	39	97
9.5 - 9.9	3	8	10	24
10.0 - 10.4	5	8	4	5
10.5 - 10.9	0	3	1	2
11.0 - 11.4	0	0	0	3
11.5 - 11.9	0	0	0	0
12.0 - 12.4	0	0	1	0
Mean (inches)	8.05	8.04	8.47	8.42

section this was considered not to be an important source of error. Another possibility was that since an entire pectoral fin was removed for a mark at this time, there was a differential mortality due to the fin removal. To test this postulate in Hemlock Lake, half of the trap-caught fish were marked by removal of a pectoral fin, while the other half were marked by clipping a corner of the caudal. The latter mark was not believed to be as potentially lethal as the former. The two estimates obtained, 3,750 and 3,711 respectively for the two marks, were nearly identical and indicated that the source of the systematic error was not in the fin removal.

Finally, it is suggested that the trout, once caught in the hardware cloth traps, acquired a "trap resistance" similar to that observed with the angler-caught fish the previous autumn. The fact that the estimates started at very high levels and then progressively decreased suggests that the trap resistance was being lost over a period of time. A final test of this hypothesis was possible by use of the Petersen method with the large samples captured on the last day of trapping, after the fish marked earlier had had a "rest." The results for both lakes, given in Table 2, showed lower estimates (and considerably narrower confidence intervals), and indicated further that the trap resistance had been lost to some degree. In Ford Lake the estimate obtained in this way, for the procedure entitled *trap and recapture by trap, last day's sample*, was 5,041, which was a considerable reduction from the estimate of 5,742 for all trapping. Similarly, in Hemlock Lake, the estimate for the pectoral clip was 3,406 and for the caudal clip was 3,206, or reductions from 3,750 and 3,711 respectively, for all trapping. It should be pointed out, however, that these reduced estimates in Hemlock Lake are still higher than the number (3,000) originally planted. It was concluded that the *trap and recapture by trap* procedure, where the hardware-cloth traps were used, was invalid because it included a systematic error which produced estimates that were too high. It should be emphasized that while the use of one type of trap (hoop net) produced an estimate known to be low, the use of another type (hardware-cloth trap) produced an estimate known to be high. The difference apparently is due to the type of trap, and it would be just as unsafe to predict the direction of error in still another type of trap (or these types in another situation) as it would be to assume the procedure to be without error. No suggestions are offered to explain the difference in the behavior of the fish with the two types of traps.

MIXED PROCEDURE ESTIMATES

In Hemlock Lake the estimates of the 1955 year class, 528 and 539, made in the autumn of 1956 by the two mixed procedures, *trap and recapture by angling* and *angling and recapture by trap* (Table 1), compared well. Furthermore, there was no error identifiable by judgment against other information such as known minimum number present or numbers planted. One systematic error, however, was soon recognized in the *angling and recapture by trap* procedure which tended to produce a high estimate. This error was due to the fact that while angling and marking was being done in the afternoon, the traps, which had been lifted and reset in the morning, were fishing; in other words, the number of angler-marked fish was increasing during the afternoon while the traps were fishing for these marked fish. The number of marked fish used in the calculation for the *angling and recapture by trap* procedure in Table 1 was the number present at the time the traps were lifted (morning), which was the number present at the close of the previous day's angling. The effective number present during the *total* time the traps were fishing (afternoon to following morning) would be something less. In an attempt to correct for this error a number midway between that present at the time angling began and that present at the close of angling was used in the calculation for the following day's estimate by the *angling and recapture by trap, M corrected* procedure (*M* equals number of marked fish).[2] The resulting estimate was 524, which was close to the estimate of 528 obtained by *trap and recapture by angling*, the other mixed procedure.

Both methods of capture, however, apparently discriminated against fish 6 inches in length and shorter, and consequently all estimates made in the autumn of 1956 were probably only of a portion of the 1955 year class. Sampling done with hardware-cloth traps and ice fishing a few months later in

[2]A better procedure would have been to postpone resetting the traps each day until angling was completed for the day.

the winter, when both methods captured many small, unmarked fish, provided a check on the autumn estimates since the caudal-clip marks were still easily distinguishable. This winter estimate was somewhat higher, and later estimates in 1957 indicated that it was more correct. This fact does not invalidate the conclusions made regarding the identification of systematic errors, since they would apply to the portion estimated as well as to the entire population as long as the size ranges available to both methods of capture were the same (Table 3). Additional estimates of the population of trout 7.0 inches in length and longer were computed by all procedures, as a further test, since apparently neither method of capture discriminated against these sizes. The relationships among the estimates were very similar to those which included all sizes. Probably the best estimate of the portion available to both methods of capture of the 1955 year class in the autumn of 1956 was about 525.

In Ford Lake, in the autumn of 1956, the two mixed procedures, *trap and recapture by angling* and *angling and recapture by trap*, produced estimates (432 and 500, respectively) which appeared to reflect the systematic error in the latter procedure, particularly since the confidence intervals did not overlap broadly. The correction made in this lake was to modify the field operation by stopping angling but continuing trapping, and using only the trap samples after angling was stopped for the estimate. The corrected estimate, 465, is shown in Table 1 for the *angling and recapture by trap, M constant* procedure, and which compares more favorably with the other mixed estimate of 432. Apparently, the best estimate would be about 450. The error shown up in Hemlock Lake by the winter check was not believed to be present in Ford Lake because the fish were larger than in Hemlock (Table 3) and therefore presumably completely available to both methods of capture. Later estimates in 1957 indicated that 450 was at least a reasonable estimate.

In both Hemlock and Ford lakes in the spring of 1957, the mixed procedure estimates of the 1956 year class (Table 2) were at a more reasonable figure, in view of the numbers planted the previous autumn. These estimates were both obtained by a *trap and recapture by angling* procedure where the trapping was done first and the recapture samples obtained after the trout season opened, with the estimates being made by the Petersen method. In Ford Lake the number planted in the autumn was 5,850, and the *trap and recapture by angling* estimate in the spring was 4,410. The *Autumn 1957, check estimate* was made with recaptures made the following autumn, of fish given a permanent mark in the spring by complete removal of a pectoral fin, for estimating the population as it was in the spring. The autumn check estimate in Ford Lake (4,624) was somewhat higher, perhaps because there was differential mortality due to the fin removal, and consequently the estimate of 4,410 was considered to be the better. Similarly in Hemlock Lake, the *trap and recapture by angling* estimate, spring 1957, was 2,591 (planting was 3,000 the previous autumn), while the *Autumn* 1957, *check estimate* of 2,997 was higher. The latter estimate was felt to be too high in view of the number planted, and the estimate of 2,591 was accepted as the better.

CONCLUSIONS

Generally, the pure procedures were inferior to mixed procedures. *Angling and recapture by angling* procedures produced estimates that were considered too high, presumably because hook resistance was acquired by the fish after they were caught once. *Trap and recapture by trap* estimates, when the hoop-net type of trap was used, produced estimates which were known to be low when compared to known minimum numbers present. *Trap and recapture by trap* procedures, when hardware-cloth traps were used, produced estimates which were too high, in some cases higher even than the known number planted 6 months previously. In all cases, mixed procedures of *angling and recapture by trap* and *trap and recapture by angling* produced estimates which were compatible with information on planting and known numbers present, and which agreed favorably with each other.

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Recaptures of Adult Largemouth Bass from the St. Johns River, Florida

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ABSTRACT

Four thousand two hundred and ninety-eight native largemouth bass were tagged and released in Lake George, a wide area of the St. Johns River, Florida, near its mid-section. Recoveries of 333 fish were made with nets in Lake George during the period of release, and 189 were reported by anglers from the river system during 7 years. Sport fishermen returned more marked fish in late winter and spring than during other seasons. It is suggested that the Lake George largemouth bass population may consist of a resident segment with restricted ranges, and of a mobile group which tends to move more freely through the St. Johns River. More large bass than small bass were recaptured from points where they were released. The percentages recaptured in Lake George away from their points of release were approximately equal for both size groups. A larger percentage of recoveries from areas in which fish were released was found during winter than during fall months. Within the first year after release at least 30 percent of the anglers' returns were made from areas beyond Lake George. Recoveries by sport fishermen were made as far as 60 miles upstream and 123 miles downstream from the points of release. Downstream returns included recoveries from highly saline waters near the river mouth.

INTRODUCTION

Knowledge of the movement of adult largemouth bass *(Micropterus salmoides)* in a river should prove useful to management of this species. The present study of natural movement was made in the St. Johns River, Florida. Dequine and Hall (1950) recorded that some movements of largemouth bass occurred between connected lakes in central Florida, but were unable to discern a pattern of migration. Freeman and Huish[1] reporting on later tagging studies made in two of the same lakes also found inter-lake movement by largemouth bass. Moody (1957) reported returns of largemouth bass, tagged in Lake Panasoffkee, from the connecting Withlacoochee River and from tributary streams of the Withlacoochee watershed, sometimes at long distances from their points of release.

The St. Johns River in northeastern Florida is approximately 300 miles long and flows in a northerly direction (Figure 1). Since the stream gradient from source to mouth is about 20 feet, the current is sluggish. Conditions of low rainfall, strong winds, and tides cause a daily reversal of flow along the lower half of the river's length (McLane, 1955)[2]. The St. Johns River, which originates from rainfall over marshy areas, is fresh at its source. More than 60 miles downstream ancient marine deposits begin to contribute salt to the water. Here river banks and channels become more distinct and lakes which are formed assume more definite shorelines. Three large lakes of the river in this area are lakes Harney, Jessup, and Monroe, with areas of 9, 12, and 14 square miles respectively (Moody, 1954). Lake George, downstream from Lake Monroe, is the largest and widest lake formed by the St. Johns River. It is 6 miles wide, 12 miles long, and is relatively shallow. The bottom slopes gently from the shore to depths of 8 to 12 feet in central areas. The lake is located approximately 120 miles from both the headwaters and the mouth of the St. Johns River.

Salinities of Lake George water vary with rainfall and flow direction between 80 and 408 p.p.m. chloride. They are partly due to old marine deposits, some of which are present along the southeast side of the lake, and partly to the discharge of three constant-temperature springs which empty into Lake

[1]Freeman, Barry O., and Melvin T. Huish. (MS.) A summary of fish population control investigations conducted in two Florida lakes. Florida Game and Fresh Water Fish Commission, 109 pp. (Mimeographed report).

[2]McLane, William M. (1955) The fishes of the St. Johns River System. Ph.D. dissertation, University of Florida, 362 pp.

FIGURE 1.—Areas of recapture in the St. Johns River system of largemouth bass released in Lake George (widest central part of river).

George from the west. The chloride contents of two of these, Silver Glen and Salt Springs, were 610 and 2,800 p.p.m., respectively, in 1946 (Ferguson *et al.*, 1947). A few miles downstream from Lake George the 125 mile-long Oklawaha River discharges large quantities of fresh water into the St. Johns River. From a point approximately 20 miles below the entrance of the Oklawaha River salinities gradually increase. McLane[3] states that in the vicinity of Jacksonville they range from 900 to 9,600, and at the mouth from 11,400 to 20,000 p.p.m. chloride.

MARKING AND RECOVERY PROCEDURE

Four thousand two hundred and ninety-eight native largemouth bass, tagged from October 3, 1952, to February 28, 1953, by methods similar to those described by Dequine and Hall (1950), were released at 43 locations in Lake George. These fish were captured in 1,600-yard haul seines and were tagged, measured, weighed, and immediately released at the sites of capture. The identifying serial number of the metal strap tag applied to the maxillary bone was recorded with total length (to the nearest half an inch), weight in pounds and tenths, and date and locality of release. On a few occasions measurements and/or weights were not obtained. Tagged bass were liberated from all areas of Lake George.

Few small bass were obtained for tagging because the nets had a minimum stretch measure of 3¾ inches. Three-tenths of 1 percent of the measured fish were 10.5 and 11.5 inches (0.6 and 0.8 pound, respectively), 4.9 percent were 12.0 to 13.0 inches (0.9 to 1.0 pound), 61.5 percent were 13.5 to 16.5 inches (1.1 to 2.3 pounds), and 33.3 percent were 17.0 to 27.5 inches (2.6 to 15.0 pounds) in length.

Publicity was given to the tagging program through newspaper releases and display of printed signs at sport camps and elsewhere. It requested that tag number, length, and weight of recaptured fish be reported with date and location of catch. Selection of returns for analysis was carefully made. Date of recovery had to be established to the month, and locality with an accuracy of ½ mile. Distances between release and recapture points were measured as straight lines on United States Coast and Geodetic Survey charts and on county maps. Correspondence and personal interviews frequently helped complete information on returns. This study is based on 189 verified returns by sport fishermen from the St. Johns River system over a period of nearly 7 years, and on 333 recaptures from the haul seines operated in Lake George during the period of tagging.

FREQUENCY OF ANGLERS' RETURNS

Returns made within 1 year after tagging were more numerous than in succeeding years. One hundred and thirty-four returns (70.9 percent) were made within the first year, 35 (18.5 percent) during the second, 10 (5.3 percent) in the third, and 10 (5.3 percent) during the following 4 years. These results are in agreement with other reports of large

[3]See footnote 2.

mouth bass tagging studies in Florida and elsewhere (Dequine and Hall, 1950; Chance, 1955; Kimsey, 1957; Moody, 1957; and others). Recaptures reported after the first year were made during the annual period of high angler success suggested by the returns of the first year. The period of greater returns began in February and reached a maximum during the months of March and April. The trend followed rises in average temperature until March and April but declined with further temperature increases (Table 1).

Creel-census data reported from Lake Panasoffkee in Florida show a similar relationship between temperature and numbers of anglers fishing for bass. The period of high fishing pressure began in January, approached maximum proportions during the months of March and April, and decreased with further temperature rises after May (Moody, 1957). The reproductive period of largemouth bass in Florida begins early and is of protracted duration. Bass have been observed to spawn in the St. Johns River in January and to continue until May (McLane, 1948). The period of high returns seems to have been related to factors associated with the time of spawning which also may have influenced fishing pressure.

DISTANCES TRAVELED AND TIME LAPSE BETWEEN RELEASE AND RECOVERY

Single recaptures of 307 largemouth bass from Lake George in the nets during the 5-month period of release included 218 (41.7 percent) returned from the points (within 1 mile) of release. Twenty-five additional marked fish from the haul seines were recaptured twice, and one, three times. Eleven (44.0 percent) of the twice-recaptured bass were returned both times from their points of release. One fish (4.0 percent) was recaptured once from the release point, and once 10 miles from that area. The single fish recaptured three times was taken each time at a different location in Lake George. During the same time period anglers reported 18 recaptures from Lake George, of which 7 (38.9 percent) were returned from their points of release. These returns are in agreement with previous conclusions that populations of certain fresh-water fish species, including largemouth bass, may consist of sedentary or resident groups whose movements are restricted to limited areas, and of mobile groups which range more widely through a drainage system (Funk, 1957).

Anglers' returns from below Lake George included one fish recaptured near the mouth of the St. Johns River, 123 miles from its point of release. Many scattered returns were made in the area between the lake and the river mouth. Numerous recoveries were made upstream from Lake George, one of which was at a maximum distance of 60 miles from its point of release. No returns were made from St. Johns River above Lake Harney where there are marked ecological differences from the river below that point.

Returns from distances of 10 miles or less included recoveries from Lake George and comprised 61.9 percent of the 189 verified recaptures reported by anglers (Table 2). Seventeen and five-tenths percent were made from distances greater than 20 miles, and

TABLE 1.—*Monthly and annual returns of largemouth bass released in Lake George and average monthly water temperatures (degrees Fahrenheit) in the St. Johns River at Sanford*

Month	Year								Total	Average water temperature[1]
	1952	1953	1954	1955	1956	1957	1958	1959		
January	—	3	1	—	—	—	—	1	5	62.6
February	—	19	4	3	—	2	—	—	28	63.5
March	—	31	6	—	3	1	—	—	41	68.0
April	—	26	10	1	2	—	—	—	39	74.3
May	—	18	5	2	—	—	—	—	25	80.6
June	—	13	2	1	—	—	—	—	16	84.2
July	—	3	4	—	—	—	—	—	7	86.0
August	—	3	2	—	—	—	—	—	5	85.1
September	—	3	1	—	1	—	—	—	5	83.3
October	1	4	2	1	—	—	—	—	8	76.1
November	1	2	—	—	—	—	—	—	3	68.9
December	2	4	—	1	—	—	—	—	7	63.5
Total numbers	4	129	37	9	6	3	—	1	189	—

[1]Averages of daily maximum and daily minimum water temperatures over the 25-year period January 1930 to December 31, 1954 (McLane, 1955, see footnote 2).

TABLE 2.—*Percentages of largemouth bass returned at various distances from points of release in Lake George*

Distance from release point	Percentage returned
One mile or less	23.3
1 - 5 miles	16.9
6 - 10 miles	21.7
11 - 20 miles	20.6
21 - 40 miles	7.4
41 - 60 miles	6.4
60 - 123 miles	3.7

3.7 percent from distances of 60 to 123 miles from points of release. Dequine and Hall (1950) found from a tagging study in the Apopka-Griffin lake complex that there were no recoveries from distances greater than 13 miles from the points of release. Maximum distances from release to recovery locations reported for largemouth bass in Missouri ranged from 25 to 50 miles (Funk, 1957).

Recaptures reported downstream from Lake George were made at greater average distances from points of release than recaptures upstream (Table 3). Returns from areas in which fish were released were made through a longer average time than returns made in Lake George away from points of release. Average distances traveled by fish taken in Lake George away from the point of release and in lake tributaries, were directly proportional to average time between release and recovery. Returns from areas of the St. Johns River upstream and downstream from Lake George, and from tributaries of the St. Johns River showed similar relationships (Table 3).

TABLE 3.—*Average number of days and average distances between release and recovery for returns of largemouth bass tagged in Lake George*

Area of recovery	Average days	Average miles
At release point	212.0	0.0
Away from release point in Lake George	200.3	5.5
Upstream from Lake George	292.3	25.9
Downstream from Lake George	445.2	40.1
Tributaries of Lake George	362.1	9.5
Tributaries of St. Johns River	339.8	32.8

FACTORS AFFECTING LOCATION AND TIME OF RECOVERY

The returns indicate that bass travel freely about Lake George and probably enter as well as leave the lake. During the 7 years in which recaptures were made, 20 (10.6 percent) recoveries were made upstream, 33 (17.5 percent) downstream, 15 (7.9 percent) in tributaries of Lake George, and 5 (2.6 percent) in tributaries of the St. Johns River.[4] The 116 returns made from Lake George represented 61.3 percent of the total number of recoveries (Table 4). Fishing pressure is greater in the St. Johns River than in Lake George. Under conditions of more equal fishing load the ratio of returns from the lake to returns from other areas of the St. Johns River would probably have been larger than is shown on Table 4. During the first year after release 88 (65.6 percent), during the second, 20 (60.9 percent), and during the third, 4 (40.0 percent) of the recoveries were made within Lake George (Table 4). Because increasing effects of dispersal, mortality, and other factors after the first year introduce errors, returns made within 1 year of release are considered to be more indicative of behavior patterns than later recoveries.

Largemouth bass released in north, south and west sections of the lake showed identical percentages of returns (69.2 percent) within 1 year of release from Lake George (Table

[4]Three returns, one 60 miles upstream, one 85 miles downstream, and one in a tributary 14 miles from release points in Lake George, were made 40, 123 and 2 days after their respective dates of release. These bass measured 14.5, 13.5, and 13.5 inches, respectively, when released.

TABLE 4.—*Annual returns from largemouth bass released in Lake George and recovered in different areas*

Area of recovery	Years between release and recovery						
	0-1	1-2	2-3	3-4	4-5	5-6	6-7
Lake George							
Near release point	29	11	3	0	1	0	0
Away from release point	59	9	1	1	1	0	1
St. Johns River							
Upstream from Lake George	16	2	0	2	0	0	0
Downstream from Lake George	16	10	5	2	0	0	0
Tributaries of							
Lake George	10	2	1	2	0	0	0
St. Johns River	4	1	0	0	0	0	0
Number of returns	134	35	10	7	2	0	1

TABLE 5.—*Percentages of largemouth bass returned within 1 year after release, in various areas of recovery and release*

Area of recapture	Area of release in Lake George				
	North side	South side	West side	East side	Central areas
Lake George					
At release point	11.5	46.1	19.2	22.2	20.8
Away from release point	57.7	23.1	50.0	48.9	25.0
St. Johns River					
Upstream from Lake George	11.5	15.4	7.7	13.3	8.3
Downstream from Lake George	15.4	7.7	11.5	4.4	29.2
Tributaries of					
Lake George	3.8	7.7	11.5	6.7	8.3
St. Johns River	0.0	0.0	0.0	4.4	8.3
Number of returns	26	13	26	45	24

5). Bass released from central areas showed the smallest (45.8 percent), and bass from the east side, the largest (71.1 percent) proportion of recaptures from the lake. The largest percentage of largemouth bass returned from their points of release were released on the south side, and the smallest, on the north side of Lake George.

Except for central areas, frequency of recaptures beyond Lake George consistently decreased with increasing distances from areas of release. Bass released on the north side showed a higher percentage of recaptures downstream than bass released on the south side of the lake. Bass released from the west were recaptured in tributaries of Lake George with greater frequency than bass released on the east side. Releases from the east side, however, were recaptured with greater frequency upstream than downstream from Lake George. The highest percentage (29.2) of returns made downstream in the St. Johns River was of fish released in central areas (Table 5).

An arbitrary separation of first-year returns by length classes at time of release shows the effect of size on location of recapture (Table 6). Large bass were twice as likely to be taken at their points of release as small bass. Percentages of large and small bass taken in Lake George away from their release points were nearly equal. The percentage of large fish recaptured from the St. Johns River was less than the percentage of the smaller size group. Percentages of recaptures in tributaries for the smaller and the larger sizes were nearly the same with 10.9 and 10.5 percent, respectively (Table 6).

TABLE 6.—*First-year returns of largemouth bass of different lengths at time of release, expressed as percentages recaptured in the areas of the St. Johns River system*

Area of recapture	Length range in inches	
	11.0–16.0	16.5–25.0
Lake George		
At release point	15.1	29.8
Away from release point	43.8	42.1
St. Johns River		
Upstream from Lake George	11.0	14.0
Downstream from Lake George	19.2	3.5
Tributaries of		
Lake George	8.2	7.0
St. Johns River	2.7	3.5
Number of returns	73	57

TABLE 7.—*Percentages of largemouth bass released and returned during the periods October 3 to December 31, and January 1 to March 31, expressed by areas of recovery*

Area of recapture	Time interval	
	Oct. 3–Dec. 31	Jan. 1–Mar. 31
Lake George		
At release point	14.3	55.6
Away from release point	42.8	33.3
St. Johns River		
Upstream from Lake George	28.6	2.8
Downstream from Lake George	14.3	2.8
Tributaries of		
Lake George	0.0	5.6
St. Johns River	0.0	0.0
Number of returns	7	36

A comparison of returns during the fall and winter seasons of release shows that a much larger percentage was recovered at the points of release in winter (55.6 percent) than in fall (14.3 percent) months (Table 7). The winter season coincided with the beginning of the spawning period. Recaptures beyond Lake George were made with greater frequency during the fall (42.9 percent) than during the winter (11.2 percent).

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Chemical and Histological Studies of Wild and Hatchery Salmon in Fresh Water

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ABSTRACT

In a study of coho salmon *(Oncorhynchus kisutch)*, the gross chemical and histological changes occurring over a 14-month period spent in fresh water were determined. The determinations were made at 3-month intervals on: 1) hatchery-reared fish, 2) fish hatchery-reared for 3, 6, 9, and 12 months and then planted in a controlled stream for the remainder of the period; and 3) an indigenous group of wild fish in this stream. Wild fish showed high incidence of tissue damage from spinose hairs of the moth larva, *Halisidota argentata*. Hatchery fish were similarly affected with the severity and incidence of lesions varying directly with the time of exposure of the larvae in the wild environment. Both groups of fish were heavily parasitized by sporozoan organisms in the kidney and spinal cord. Kidney disease appeared in both wild and planted hatchery fish. The gross chemical composition of hatchery fish transformed rapidly after planting to that of the wild fish. Although the initial rate of fat loss is essentially constant for all hatchery groups after planting, fish that were hatchery reared for 9 to 12 months did not complete the transformation to the wild-type body composition by the time of downstream migration at 14 months.

INTRODUCTION

With the encroachment of civilization on the natural spawning grounds of salmon, the perpetuation of these species depends to an increasing extent on various methods of artificial propagation. The evidence on the relative survival of hatchery-reared and wild salmonids is contradictory (Klak, 1941; Williamson and Schneberger, 1943; Schuck, 1948; Miller, 1952, 1954, 1958; Nielson *et al.*, 1957). Additional evidence regarding the two groups is necessary for proper interpretation of survival data. The purpose of this paper is to report chemical and histological characteristics of hatchery fish after living for variable periods in a hatchery environment, the changes which occur in fresh water after transition to a wild environment, and the comparison between hatchery-reared fish and a similar group of wild fish.

Salo and Bayliff (1958) have reported a series of carefully controlled studies in which the survival of artificially reared coho salmon *(Oncorhynchus kisutch)* was compared to the survival of wild coho salmon from the same parent stock over a period of 17 years. These fish spend their first year in fresh water, and may be maintained under artificial conditions for the entire period if desired. They then migrate to the ocean for a 2-year period and return to spawn. Their survival studies were, therefore, concerned with both fresh water and marine survival. A major objective of the hatchery operations was to protect the young salmon during their fresh water cycle. This report stated that approximately 90 percent of these fish died in fresh water if they were released at 2-3 months of age. Mortality was reduced to approximately 40 percent if the fish were reared for 14 months. There was thus an apparent advantage to the increased period of hatchery protection. In the ocean, however, the fish released at 2-3 months showed a survival ranging up to 10 percent while those reared for 14 months had a survival considerably below 1.0 percent, and much of the advantage gained by the added protection in fresh water was lost.

The survival of wild fish fluctuated widely with an approximate maximum of 10 percent in fresh water and 7 percent in salt water. The mortality in the ocean was definitely less in wild fish than in hatchery fish reared for periods of 12-14 months (Salo and Bayliff, 1958). During the first year in fresh water, the wild fish were exposed to forces of selection which permitted only the most vigorous to survive. Several workers have pointed out that the low comparative survival of hatchery fish is due to the absence of

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natural selection at early stages in the life history (Miller, 1954; Wales, 1954). Others have felt that domesticated fish, even though they are compelled to make rather drastic adjustments, are capable of equal or better survival than wild fish (Nielson *et al.*, 1957).

The comparative environmental influences on the two groups while in fresh water constitute an additional variable which requires investigation. Great differences exist between artificial diets of hatchery fish and natural foods of wild fish, and these differences in nutrition directly influence the composition and condition of the fish which consume them (Phillips *et al.*, 1955; Wood *et al.*, 1957). Little information is available, however, on the changes which occur in the body composition of hatchery salmon after they are released.

METHODS AND MATERIALS

This study was conducted at the Minter Creek Biological Station of the Washington Department of Fisheries utilizing the same facilities as those described by Salo and Bayliff (1958). The chemical and histological studies were done at the Western Fish Nutrition Laboratory, U. S. Fish and Wildlife Service, Cook, Washington. Growth and survival studies, as well as all sampling, were done by Washington Department of Fisheries personnel, and have been reported separately by Noble.[3]

Coho salmon from the same parent stock were hatchery reared for periods of 3, 6, 9, and 12 months. At the end of each period, these fish were sampled and planted in Minter Creek where an indigenous population of wild coho salmon of the same age from the same parent stock was developing naturally. At the time of each planting, except at 12 months, the population of the stream was sampled to obtain representative specimens of the wild group and of each previously planted hatchery group. Just before the fish migrated to the ocean at 14 months of age, all groups were again sampled.

The histological material was fixed in Bouin's solution and neutral formalin. Routine paraffin sectioning techniques were used to cut whole longitudinal sections from small fish under 2 inches. Larger specimens were dissected and sections prepared from the eye, gill, heart, skin and muscle, anterior kidney, posterior kidney, liver, spleen, and stomach and caecal section of the intestinal tract. Hematoxylin and eosin were used routinely and, where indicated, Giemsa, Gram, Schiff, glycogen, and fat stains were utilized. The tissue sections were evaluated for liver fat, pancreatic and viceral fat, indications of disease as manifested in inflammatory or necrotic lesions, and for degree of parasitism.

Samples for chemical study were preserved by two methods. From 150 to 500 grams of whole fish, depending on size and availability of fish, were homogenized in a Waring blendor with two parts by weight of a 2:1 chloroform-methanol solution, and stored in pint jars. Samples of equal size were quick-frozen and later transferred to quart jars where they were held under nitrogen at —10° C. Proximate analysis values were obtained as follows: protein by macro Kjeldahl, lipid by chloroform-methanol extraction, and ash by standard ashing techniques. The homogenized and frozen samples gave values in close agreement. Details of the analytical procedure were reported in an earlier publication (Wood *et al.*, 1957).

HISTOLOGICAL COMPARISONS

The histological examination of the fish resulted in several interesting observations. Both wild and hatchery groups were heavily parasitized by a sporozoan *Myxidium minteri* (Yasutake and Wood, 1957) in the kidney tubules (Figure 1B). An additional heavy sporozoan infestation in the spinal cord was identified as *Myxobolus kisutchi* (Yasutake and Wood, 1957). The effects of myxosporidian infections are questionable and have been reported as entirely benign in some instances (Kudo, 1919; Davis, 1953). In the present case, however, definite kidney damage was associated with the organisms. Mature spores and trophozoites were found throughout the renal tubules, but not in the glomeruli. Not infrequently, tubule degeneration and obliteration occurred with subsequent chronic inflammatory lesions and apparent repair. The mechanism of this damage was obscure but may have resulted from simple blockage and impaction. The sporozoans in the spinal cord (Figure 1C) did not elicit a

[3]Noble, R. E. (1955) Minter Creek Biological Station progress report. Spring 1955. Part 1. The comparative fresh water condition of survival of wild and hatchery reared silver salmon, *Oncorhynchus kisutch*, at Minter Creek, Washington.

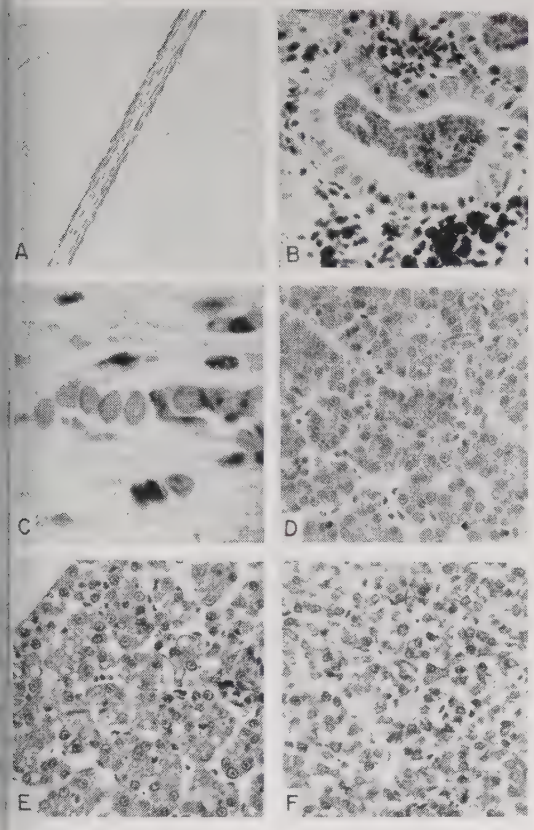

FIGURE 1.—(A) Spined *Halisidota* hair. Wet mount, 400x. (B) Sporozoans in kidney tubules. 200x. (C) Sporozoans in spinal cord. 900x. (D) Non-fatty liver of wild migrating fish. 400x. (E) Moderately fatty liver of 9-month hatchery fish at time of migration (14 months). 400x. (F) Extremely fatty liver of 6-month hatchery fish before planting. 400x. (B through F, hematoxylin and eosin preparations.)

direct inflammatory response, but there was an intense eosinophilic inflammation in the spinal canal surrounding the cord, which was probably a foreign body or allergic response. Spores occurred throughout the length of the cord, either widely scattered or in small groups. Although no apparent actual tissue damage occurred, the presence of these proliferating organisms in this highly vital and sensitive tissue was regarded as significant.

An additional unique type of tissue damage was caused by the ingestion of the moth larva, *Halisidota argentata* Packard (Figure 1A). The spine hairs from these larvae penetrated the stomach and intestinal walls and worked in a porcupine-quill fashion throughout the tissues of affected fish. The pathology of this condition has been described elsewhere (Wood and Yasutake, 1956a). Kidney disease, as characterized by the presence of gram-positive diplobacilli (Earp *et al.*, 1953) and systemic granulomatous lesions (Wood and Yasutake, 1956b), was observed in both wild and hatchery fish.

The wild fish showed incidence of markedly consistent tissue damage from the *Halisidota* hairs. The hatchery group planted at 3 months showed slight damage before planting, but after 3 months in the stream environment, the lesions increased markedly. The 6-month group had no initial lesions, but developed moderate lesions after 3 months of stream life. When the salmon migrated at 14 months, the wild fish were heavily affected, and there was a direct relationship between the tissue damage in the hatchery fish and their period in the stream environment. The groups planted at 9 and 12 months were not affected by *Halisidota* hairs. The data suggest that the larvae were emerging about June 1 and subsequently became less available to the stream fish.

The kidney sporozoan lesions were of about equal severity in the two groups. In fish under 9 months of age, the incidence of infection was nearly 100 percent, the parasite appeared more viable, and the trophozoites were actively producing spores. At the time of migration, however, the sporozoans were seen less frequently and were in an apparent stage of regression. Many small foci of granulomatous tissue marked areas where tubule debris was being removed from the kidneys of the migrating fish. The sporozoans in the spinal cord also appeared more frequently and in greater concentrations in the younger fish. The incidence was over 50 percent in both groups.

The incidence of kidney disease was low (less than 10 percent) but followed a rather interesting distribution. The disease is known to occur sporadically in the hatchery population at the Minter Creek station where it is treated with antibiotic therapy. Before planting, however, the hatchery fish did not show any evidence of the disease. Three months after the initial plant, the disease was observed in two wild fish, and subsequently was seen in one 3-month hatchery fish after a 6-month stream residence, and in one 6-month hatchery fish after a 3-month stream residence. Since we have never before noted kidney disease in wild fish, and since the disease is endemic in the hatchery population,

there is at least an indication that it is being transformed to the stream environment where it subsequently developed in both groups.

In general, the data suggest that the wild fish in Minter Creek are heavily parisitized, and affected to an unusual degree with a peculiar tissue damage caused by larval moth hairs. The significance of the observed pathology is obviously questionable, but merits further investigation. The fluctuation in mortality observed in these fish from year to year may be correlated with the cyclic fluctuations in abundance of *Halisidota*. The much heavier tissue damage observed in the hatchery group planted at 3 months may also be responsible for a greater mortality in this group than in others (Salo and Bayliff, 1958). During the period of these studies, the *Halisidota* population was apparently at a cyclic peak. The moth larvae were observed by the thousands in the foliage along stream banks and in adjacent orchards where they caused heavy damage. In the following year the larvae could be located only after diligent searching. Unfortunately, there are no available records on the annual abundance of these larvae which could be compared with the salmonid mortality observed by Salo and Bayliff (1958).

The foregoing discussion deals almost entirely with possible factors influencing mortality in fresh water, but leaves unanswered their relation to ocean mortality. The decreasing incidence of *Halisidota* damage and kidney sporozoans in migrating fish apparently removes them from consideration. As little evidence of a differential occurrence of the spinal cord organism was noted, any hypothesis of activity during ocean life would necessarily affect both groups equally. A clue to the ocean mortality may reside, however, in the comparative condition and body composition of the two groups.

The histological studies provided an index to the general condition of the fish. The wild fish had slightly fatty or non-fatty livers (Figure 1D), and slight or no pancreatic and visceral fat (Table 1). The hatchery fish at the time of planting had fatty livers and large amounts of visceral fat. After 3 months of stream environment, the group planted at 3 months had fat content similar to the wild fish. The fat content of the 6-month group had not changed after 3 months in the stream, but was similar to the body condition of wild fish at the time of migration (14 months). The 9- and 12-month groups definitely contained more microscopically visible fat at the time of migration than did the other groups (Figure 1E). The reason for the low value observed in the 12-month group at the time of planting is not clear. This observation is probably a sampling error as is indicated by the increased liver-fat content of the same group after 2 months of stream life.

CHEMICAL COMPARISONS

The chemical analysis of the various groups summarized in Table 2 confirms the trends shown by the histological analyses. The protein and fat composition of the two groups is illustrated in Figure 2. After 3 months of hatchery feeding, the percentage of fat in hatchery fish was almost triple that observed in wild fish, and the percentage of protein in the hatchery group was significantly low. Changes that took place after planting hatchery fish are shown in Figure 3. An immediate and drastic fall in percentage of fat and a concurrent rise in percentage of protein occurred in all groups. After 3 months of stream

TABLE 1.—*Liver and pancreatic fat in relation to time spent in the wild or hatchery environment*

Age	Amount of fat[1] in fish released at									
	Wild		3 months		6 months		9 months		12 months	
	Liver	Pancreatic	Liver	Pancreatic	Liver	Pancreatic	Liver	Pancreatic	Liver	Pancreatic
3 months.....	††	†	†††	††	—	—	—	—	—	—
6 months.....	†	†	†	†	†††	†††	—	—	—	—
9 months.....	††	††	††	††	†††	†††	††††	†††	—	—
12 months[2].....	—	—	—	—	—	—	—	—	†	††
14 months.....	†	†	†	†	†	††	††	†††	††	†††

[1]†—very little fat; †† moderately fatty; †††—very fatty; ††††—excessively fatty.
[2]Stream sample not available.

TABLE 2.—*Proximate analysis of protein, lipid, and ash content of wild fish and fish retained in the hatchery for various lengths of time before planting*

[Percentage of dry weight]

Analysis and age	Wild	Composition of fish released at			
		3 months	6 months	9 months	12 months
Protein					
3 months	80.1	65.4	—	—	—
6 months	76.0	78.4	58.8	—	—
9 months	73.8	71.9	72.5	65.0	—
12 months[1]	—	—	—	—	67.3
14 months	81.1	79.9	79.5	75.7	76.0
Lipid					
3 months	9.6	26.1	—	—	—
6 months	12.1	9.6	33.2	—	—
9 months	15.0	9.9	16.3	24.8	—
12 months[1]	—	—	—	—	23.9
14 months	8.6	8.2	9.4	13.4	12.7
Ash					
3 months	12.8	12.3	—	—	—
6 months	13.3	16.1	9.2	—	—
9 months	12.4	15.6	13.2	11.2	—
12 months[1]	—	—	—	—	11.2
14 months	13.8	15.6	14.7	14.8	14.9

[1]Stream samples not available.

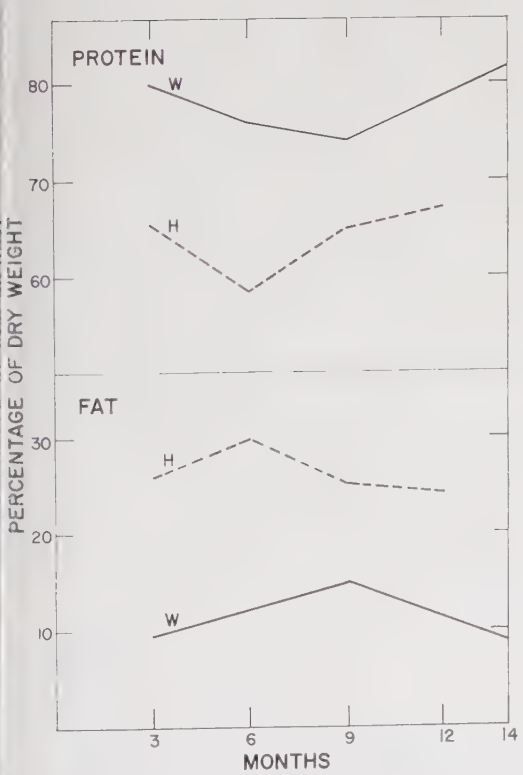

FIGURE 2.—Protein and fat levels of wild fish (W) and hatchery fish (H) at different intervals before planting.

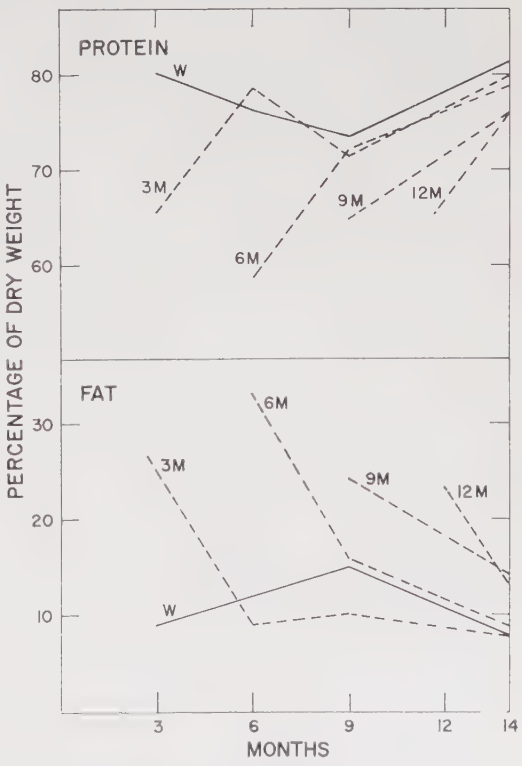

FIGURE 3.—Changes in protein and fat levels which occur in hatchery fish subsequent to planting after retention in the hatchery for 3 months (3M), 6 months (6M), 9 months (9M), and 12 months (12M); (W) wild fish during same period.

life, the composition of the hatchery fish planted at 3 and 6 months closely approximated that of the wild fish. As previously observed, the 9- and 12-month hatchery groups did not complete the transition by the time of migration at 14 months. The 9- and 12-month groups which failed to complete the transformation to the wild-type body composition at the time of ocean migration suffered the heaviest ocean mortality (Salo and Bayliff, 1958).

There are many ways in which differences of body composition affect physiological processes and in turn, survival. Hoar *et al.* (1949, 1952) have successfully correlated the degree of fatty acid unsaturation with ability of goldfish *(Carassius auratus)* to resist low as well as high temperatures. Other workers have reported evidence that fish on hatchery diets are characterized by more highly saturated fatty acids than are wild fish (Phillips *et al.*, 1949, 1950). The degree of saturation of fatty acids is only a single factor which could influence survival. Others doubtlessly exist in fish which have been raised on diets markedly different from those which they would use under natural conditions. Salo and Bayliff (1958) noted that fish raised for 14 months appeared to be "over-reared" although they did not elaborate on the term. They also observed, however, that hatchery techniques had changed sufficiently during the period covered by their data (17 years) to produce a fish weighing twice as much in 1952 as fish of the same age weighed in 1938. It is apparent that these differences in hatchery management may have been important variables in the observed survival.

The average proximate analysis of the diet fed to fish in this study was: protein—61.8 percent; lipid—23.1 percent; ash—16.4 percent. It was typical of the moderately high fat diets generally fed to salmonids on the Pacific Coast (Wood *et al.*, 1957). This diet was fed to the young fish at the rate of 8 percent of their body weight per day. As the fish grew larger, the rate of feeding was reduced until it finally reached 1.0 percent of the body weight per day after approximately 7 months of feeding. The fat content of these fish increased steadily until the lowest level of feeding was reached. Even at the 1.0 percent level, the fat content of the hatchery fish was maintained at a level far above that of the wild fish (Table 2). The precise effect on survival which differences in body composition exert must be a problem of continuing studies, if hatchery fish are to supplement natural propagation successfully.

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We are indebted to Miss Effie White, Mrs. Charlotte Hale, and Mr. Ernest Shanks for technical assistance in the histological preparations and chemical analysis.

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SHORT PAPERS AND NOTES

Survival and Growth of Tagged Lake Trout in South Bay, Lake Huron

In view of the possibility of control of the sea lamprey and the subsequent need for reintroduction of lake trout (*Salvelinus namaycush*) into the upper Great Lakes, any data that have a bearing on the survival, growth rate, and behavior of hatchery-reared lake trout in Great Lakes waters should be documented. For the past 10 years the Ontario Department of Lands and Forests has been studying planted lake trout in South Bay in northern Lake Huron. Fry and Budd (1958) showed that estimated survival of planted lake trout to age-group IV has varied between 2 and 40 percent. Each introduced year class completely disappeared from the catches of experimental gear long before any females had attained maturity normally reached at age-group VII. Data clearly showed that the sea lamprey was responsible for the early loss. Even though the planted fish were of Lake Superior origin, no differences in distribution or behavior from that observed for the original native population were noted. Growth was equal to or greater than estimates obtained from the native lake trout population that persisted in South Bay until 1951.

In November 1955, 89 tagged yearling lake trout were planted in South Bay. These fish were the largest individuals selected from a planting of 15,700 made in October of the same year. Since they were approximately 20 months old and were reared to the end of their second summer according to standard hatchery procedure, they should be comparable to any hatchery stock of a similar age and size. Streamer tags attached through the anterior base of the dorsal fin with stainless steel or tantalum wire, and Petersen tags attached through the back below the dorsal fin by heavy monofilament nylon with fused ends (Randall, 1956), were used. Individual lengths were recorded at time of tagging.

From August 1956 to June 1959, 35 of these tagged fish were recaptured in South Bay with standard pound nets and graded-mesh experimental gill nets (Table 1) durin the course of routine netting operations. Som of the tagged fish were released alive, but sub sequent recaptures were not used in calcu lating survival and were not numerous enoug to allow a direct estimate of the number c tagged fish present. Fifteen tagged fis captured for the first time were taken i 1956, 15 in 1957, 4 in 1958, and 1 in 195 From these figures minimum survival to eac age through 5 years was calculated, using th virtual population method (Fry, 1949). Sinc 35 individual fish were recaptured, some a each age through 5 years, all of these fish wer present in 1956 at age-group II. This numbe represents a survival of 39.3 percent to age group II. Fifteen fish were removed at age group II, leaving a minimum of 20 that sur vived to age-group III, or 22.5 percent sur vival. Calculated in the same manner, survival to age-group IV and age-group V was 5. and 1.1 percent, respectively.

It is perhaps desirable to attempt estimate of maximum survival. Data presented by Fr (1953) and Fry and Budd (1958) show tha for years when population estimates wer possible, the actual catch of trout of all age in South Bay was roughly 25 percent of th estimated number present. By using thi value, it can be postulated that four times th 15 fish taken at age-group II, or 60 instead c 35 fish, could have been present. This est mate gives a survival value of 67 percent t age-group II. Two biases must be considere in viewing this estimate. Fish bearing tags ar

TABLE 1.—*Number of tagged yearling lake trout r captured from releases in South Bay*

Tag and material	Number tagged	Year of recapture				Total	Per-centage
		1	2	3	4		
Streamer							
Stainless steel wire	16	2	4	1	—	7	43.7
Tantalum wire.....	31	5	5	1	1	12	38.7
Petersen							
Fused mono-filament nylon...	42	8	6	2	—	16	38.1
Total.....	89	15	15	4	1	35	39.3

more vulnerable to capture in gill nets than untagged fish. Since all of the age-group II fish were captured in gill nets, survival would therefore tend to be underestimated. It is known, however, that age-group II fish are not normally taken in proportion to their abundance even in graded gangs of gill nets that contain mesh sizes suitable for capturing them. This tendency would make the 25 percent figure too large and would indicate a greater survival to age-group II. The effect if these biases cannot be measured.

It is probably more reasonable to consider the catch at age-group III in the manner suggested above, since recaptures were made in both pound and gill nets, and age III fish are normally taken more in proportion to their true abundance than are age-group II fish. If 25 percent of the fish present in 1957 at age-group III were taken in that year, an estimate of 60 fish, or 67 percent survival to age-group III, is obtained. If this estimate is acceptable, it is then possible to add the 15 fish removed at age-group II and get a revised estimate of survival to age-group II of 75 fish, or 84.2 percent.

The capture of four fish at age-group IV and one fish at age-group V gives estimated survivals of 16 (18.0 percent) and 4 (4.5 percent) fish to these ages. It is apparent that a significantly greater mortality had occurred at an age when minimum mortality might be expected. It is certain that this increase in mortality can be attributed to an increase in lamprey predation as the fish move into the size range where they become fully vulnerable to the sea lamprey (Fry and Budd, 1958).

Table 2 summarizes the growth data obtained from the tagged fish. The growth rate was very similar to that obtained from scale measurements on a much larger sample representing several year classes of planted yearling lake trout taken in South Bay (Fry and Budd, 1958). The 89 fish averaged 8.3 inches in fork length (Table 2) and ranged from 7.2 to 10.5 inches at time of planting. There was no tendency for the larger individuals to be better represented among those subsequently recaptured. The 15 fish taken during the first summer and fall after planting averaged 12.2 inches in length and had added a mean increment of 3.7 inches in less than 1 year from the time of release. The fish taken the second summer and fall averaged 15.3 inches in length. This increase in length represents a mean increment of 7.1 inches subsequent to the time of planting. Since six of the fish were taken in June and July, growth for a full 2-year period would be somewhat greater than that indicated. The four fish taken during the third summer at age-group IV added a mean increment of 10.1 inches in less than 3 years after planting, and would have been fully vulnerable to either an angling or commercial fishery. A single fish 22.7 inches in length was taken in June 1959 at age-group V. It had grown 14.3 inches in the 44 months since release.

TABLE 2.—*Growth of tagged lake trout planted in South Bay*

Dates of planting and recapture	Number of fish	Age (years)	Mean fork length (inches)	Mean increment (inches)
November 1955 (planting)	89	1+	8.3	—
August-October 1956	15	2+	12.2	3.7
June-October 1957	15	3+	15.3	7.1
June-August 1958	4	4+	18.1	10.1
June 1959	1	5+	22.7	14.3

In summary, 35 of 89 tagged yearling lake trout were recovered over a 44-month period. The data suggest that early survival of the planted fish was good, but that as size increased, survival decreased. Growth of the tagged fish was normal with no indication that the tagging had adversely affected it. While it is recognized that no prediction of the future success of large scale plantings can be made from the limited experiment reported here, there is indication that present conditions favor early survival of introduced yearling stock.

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A Bacterial Disease of Yellow Perch *(Perca flavescens)*

On May 26, 1959, two of the authors[1] investigated a fish kill at Dailey Lake, Park County, Montana. They observed about a half-dozen live, weakly swimming yellow perch *(Perca flavescens)*, in addition to thousands of dead perch along the shoreline. It was learned from local residents that mortalities had begun to appear some 2 weeks earlier. At that time local authorities had diagnosed the condition as a winterkill, since ice had only recently disappeared from the lake. Although a number of other species inhabit Dailey Lake, including rainbow trout *(Salmo gairdneri)*, brown trout *(S. trutta)*, kokanee *(Oncorhynchus nerka)*, black crappie *(Pomoxis nigromaculatus)*, largemouth bass *(Micropterus salmoides)*, longnose suckers *(Catostomus catostomus)*, and rainbow × cutthroat hybrids, only one other species was represented in the kill. This consisted of one black crappie.

Examination of the freshly dead perch revealed the presence of multiple petechiae, which were visible externally as well as in the dorsal musculature. The peritoneal cavity showed evidence of inflammation and contained a bloody ascitic fluid. A number of the dead fish were placed on ice and shipped to the Western Fish Disease Laboratory in Seattle for bacteriological studies.

BACTERIOLOGICAL EXAMINATION

Numerous Gram-negative bacilli were found in the muscular petechiae of these fish as well as in the livers and kidneys. The organisms appeared pleomorphic. In general, however, they were short, plump, and exhibited a tendency to occur in pairs as diplobacilli.

Blood agar, heart infusion agar, and thioglycollate broth inoculated with material from the lesions, livers, and kidneys yielded pure cultures of a pleomorphic Gram-negative bacillus (Figure 1, A). The organism ranged morphologically from cocco-bacillary forms to long straight or curved rods up to 14 microns in length. Motility by means of a single polar flagellum was demonstrated (Figure 1, B). On 5 percent blood agar the colonies were hemolytic, gray in color, and

[1]Jack E. Bailey and John R. Heaton.

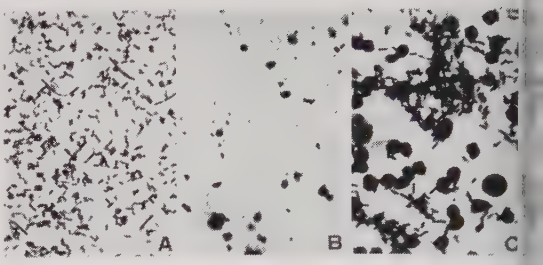

FIGURE 1. A.—Gram-stained smear from pure culture indicating pleomorphism of bacilli. 1, B.—Monotrichic flagellation demonstrated with silver impregnation stain. 1, C.—Large concentration of bacilli in kidney of fish exposed to broth suspension of etiologic agent. All cells approximately 1,500x.

extremely viscous in consistency. Colonial growth when touched with a platinum needle formed long fine strands as the needle was withdrawn. The results of carbohydrate utilization and other biochemical characteristics are shown in Table 1. Glucose utilization was shown to be fermentative rather than oxidative by the method of Hugh and Leifson (1953).

Antibiotic discs (Difco) were used to test the sensitivity of the bacterium *in vitro*. The organism exhibited sensitivity to aureomycin, chloromycetin, dihydrostreptomycin, polymyxin B, and terramycin, while penicillin and bacitracin proved ineffective. The characteristics of the bacterial organism reported here indicate that it is most closely related to the genus *Pseudomonas* despite the lack of cytochrome oxidase (Gaby and Free, 1958).

EXPERIMENTAL TRANSMISSION

Ten 6- to 8-inch yellow perch were placed in a 48- by 12- by 6-inch trough. Dechlorinated city water at an initial temperature of 44° F. was used as the water source. Five

TABLE 1.—*Biochemical reactions of organism cultured from diseased fish*

Test	Reaction	Test	Reaction
Acid from:		Acid from:	
glucose	+	dulcitol	—
trehalose	+	inositol	—
glycerol	+	lactose	—
maltose	+	levulose	—
mannose	+	Nitrite from nitrate	+
xylose	—	Gelatin liquefaction	+
mannitol	—	Indol	—
sucrose	—	Methyl red	—
sorbitol	—	Voges-Proskauer	—
raffinose	—	Citrate	—
arabinose	—	Litmus milk	slowly acid

undred milliliters of a 24-hour broth culture f the organism were introduced into the rough for a period of 30 minutes during hich time the water flow was discontinued. his procedure was repeated the following ay and again on the fifth and sixth day fol-owing the initial exposure. During this time ne treated fish exhibited symptoms of shock nd succumbed. No bacteria were seen on ained smears, nor were any isolated by cul-ural methods. Fifteen days after the begin-ing of the experiment the water temperature as raised to 50° ± 2° F. Nine fish in an djacent trough on the same water supply ere exposed to sterile broth and served as ontrols.

Four mortalities occurred in the experi-ental trough 29 days following the initial xposure. One control fish also died at this me. Two days later two mortalities were oted in the experimental trough. Stained mears prepared from the livers and kidneys evealed the presence of immense numbers f Gram-negative bacilli in the six dead fish xposed to the viable bacteria. No bacteria ere seen upon examination of similar ma-rial from the control fish. Cultures pre-ared on blood agar media from the kidneys f all the dead fish confirmed the results of he microscopic examination as no growth as obtained from the control fish while pure ultures of a Gram-negative bacillus were ob-ained from the kidneys of the six treated fish.

Three days following the last mortality ex-ernal lesions of columnaris disease appeared n the three remaining treated survivors. hese fish were sacrificed at this time in ad-ition to five control fish. No bacterial or-anisms were evident in the organs of the ontrol fish either by staining or cultural ethods. The kidney of one of the three reated fish contained large numbers of the ram-negative bacillus (Figure 1, C). Al-hough bacteria were not seen in stained prep-rations from two of the treated fish, the rganism was isolated by culture from the idney of one fish and from a small hemor-hagic lesion in the musculature of the other ish. Subsequent studies showed that the bac-eria recovered from all of the experimental ish were identical to the bacteria isolated rom the Dailey Lake perch.

DISCUSSION

The infectious nature of the bacterial agent reported here is clearly indicated by the recovery of the organism from 9 of 10 exposed fish. The disease in the laboratory differed from the disease in nature in that only one of nine laboratory infected fish manifested external petechiae. This difference, however, may be related to the mode of transmission which is unknown in the feral state. The debilitating effect of this organism upon the host is further borne out by the appearance of a secondary bacterial infection with *Chondrococcus columnaris* which manifested itself only in those perch exposed to the broth suspension containing viable bacteria. As columnaris disease is generally associated with temperatures higher than the 50° — 52° F. maximum used in the present study, this apparent synergy may be of some importance in fishery management.

The bacterium discussed in the present paper is believed to be previously undescribed. Although reports of bacterial diseases of perch are practically non-existent in the literature, Plehn (1924) reported several epizootics of *Perca* sp. occurring in Lake Geneva which she called "typhoid disease of perch". Although the causative organism itself was insufficiently described to compare with the organism in the present study, there were several striking similarities between the disease in Lake Geneva and the recent epizootic in Lake Dailey.

Plehn reported that on several occasions between March and July perch died by the thousands. The Dailey Lake epizootic occurred in May. Although eel-pout, pike, carp, and groundlings present in Lake Geneva did succumb, they did so in small numbers. Both organisms thus show a specificity for perch. While a septicemic condition was present in fishes from both areas, mortalities from Lake Geneva contained superficial gray-white spots on the external surface of the skin. In contrast, dead fish from Montana contained hemorrhagic lesions in the musculature itself. Plehn believed that unfavorable weather conditions such as a drop in temperature may have contributed to the disease outbreak. Temperature changes are not believed to have influenced the Dailey Lake epizootic. Since this lake is relatively shallow, however, depletion of oxygen during the winter may have exerted undue stress upon the yellow perch

population thus inducing a lowered resistance to the infectious agent. It has also been pointed out by Snieszko (1958) that at low water temperatures antibody production of carp in response to injections of antigen is greatly reduced. An analogous condition may exist in natural bacterial infections of other warm-water species of fish. A seasonal variation may occur, therefore, in the degree of natural resistance possessed by a host species to a bacterial agent. Further studies may indicate that at higher water temperatures, yellow perch have an increased resistance to the pathogenic effects of the bacterial organism under investigation.

Bacterial diseases of perch have apparently received little attention in the past, presumably because perch are generally considered to be trash fish (LesVeaux, 1959), and a relatively small amount of effort has been expended in their artificial propagation. El-Zarka (1959) states, however, that the yellow perch is one of the most important and widely distributed food fish of the northeastern United States and southeastern Canada. Whatever the economic role of perch, all diseases of fish should be of interest to fishery biologists, particularly when they occur in mixed populations and may potentially affect the ecology and management of a given area.

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Potassium as an Index of Naturall Occurring Radioactivity in Tuna Muscle

Determinations of radioactivity in fis muscle should take into account the amou of naturally occurring radioisotopes. It w the purpose of this study, therefore, to d velop an index for the determination of th radioisotope K^{40} from the level of stab potassium in tuna muscle. The potassiu content of fish tissues has been reported b Vinogradov (1953) and Osterhaug (1958 The determination and significance of K^{40} fish tissue has been discussed by Cherubi and Fitzgerald (1957).

The specimens used in this analysis co sisted of 52 samples of light and 50 sampl of dark muscle tissue from bigeye tuna, *Thu nus obesus* Lowe, and yellowfin tuna, *Thu nus albacares* (Bonnaterre), from the Centr Pacific. The muscle samples were ashed 500° C. for 24 hours in a muffle furnace an 200 milligrams of ash from each sample we dissolved in 1 normal nitric acid. Determi ations of stable potassium were made wi a Beckman Model DU Flame Spectr photometer (Model 4300 Photomultipli attachment with a blue sensitive 1 P2 Multiplier Tube), utilizing an oxy-hydrog flame. Preliminary trials with the flame spe trophotometer demonstrated the difficulty reducing the interference from sodium ar calcium using a wave length of 766.5 m (Wallace *et al.*, 1951). Sufficient sensitivi with no measurable interference was obtain with the potassium band at 404.6 mμ. F the analyses the spectrophotometer was o erated at this wave length, the sensitivity co trol at the mid-point, full sensitivity on t photomultiplier attachment, the select switch at 0.1, a slit opening of 0.1, and pounds per square inch of hydrogen and

pounds per square inch of oxygen for the same.

Standard solutions of 20, 50, 100, 200, and 300 p.p.m. of potassium were prepared. The percent transmittance of the 404.6 mμ band was plotted against the concentration of the standards. Over this range the relationship was linear and sample concentrations were readily determined. The amount of wet tissue represented by the amount of ash in each test sample was calculated, and the concentration of potassium determined for each sample was then expressed in milligrams of potassium per gram of wet tissue.

Flame spectrophotometric determinations of potassium in biological samples have been discussed by Burriel-Martí and Ramirez-Muñoz (1957), Bernstein (1952), Glick *et al.* (1955), Orskov (1953), and Valencia (1956).

The radioactivity to be expected from K^{40} per gram of natural potassium was calculated in the following manner:

$$d/m/g = \lambda N$$

λ = the decay constant

$$= \frac{0.693}{T_{1/2}} \text{ (Kinsman, 1954)}$$

$T_{1/2}$ = radioactive half life of K^{40} = 1.3×10^9 years

N = number of atoms of K^{40} per gram of potassium (percentage abundance of K^{40} = 0.012)

The potassium content in milligrams per gram of wet tissue and the radioactivity to be expected from K^{40} expressed in disintegrations per minute per gram of wet tissue for each sample are presented in Table 1. For light muscle the mean potassium content in milligrams per gram of wet tissue was 2.31 with a standard deviation of 0.6. For the dark muscle the mean was 2.27 and the standard deviation 0.7. The mean expected

TABLE 1.—*Potassium content (milligrams per gram of wet tissue) of light and dark muscle tuna tissues and the radioactivity to be expected from K^{40} (disintegrations per minute per gram of wet tissue)*

Sample number	Type of tuna	K content		Expected d/m/g from K^{40}		Sample number	Type of tuna	K content		Expected d/m/g from K^{40}	
		Light	Dark	Light	Dark			Light	Dark	Light	Dark
2	Bigeye	—	3.28	—	6.02	281	Bigeye	2.53	—	4.55	—
1	do	2.90	—	5.32	—	284	Yellowfin	1.96	—	3.53	—
2	do	—	1.27	—	2.33	291	do	—	3.21	—	5.78
16	do	3.97	—	7.28	—	292	do	—	2.11	—	3.80
22	do	2.33	—	4.27	—	293	do	—	2.61	—	4.70
23	do	1.95	—	3.58	—	302	Bigeye	1.78	—	3.20	—
25	do	2.78	—	5.10	—	314	do	—	2.14	—	3.92
29	do	1.77	2.26	3.25	4.14	317	do	—	1.90	—	3.42
1	do	3.57	—	6.55	—	319	do	—	2.11	—	3.80
2	Yellowfin	2.45	1.50	4.50	2.75	344	Yellowfin	2.36	—	4.25	—
31	Bigeye	—	2.06	—	3.78	367	do	2.41	—	4.42	—
5	Yellowfin	2.47	—	4.53	—	395	Bigeye	2.30	—	4.14	—
12	Bigeye	1.93	1.73	3.54	3.17	398	Yellowfin	2.07	—	3.73	—
1	do	1.72	—	3.10	—	403	Bigeye	2.11	—	3.87	—
10	do	—	2.45	—	4.50	404	do	3.06	2.21	5.61	4.05
11	do	1.65	—	3.03	—	406	do	—	1.85	—	3.39
2	do	3.05	—	5.60	—	466	Yellowfin	1.26	—	2.31	—
22	do	—	1.96	—	3.59	467	do	1.54	1.50	2.82	2.75
24	do	—	1.29	—	2.37	468	Bigeye	—	2.01	—	3.69
26	do	2.25	—	4.13	—	474	do	1.81	—	3.32	—
28	Yellowfin	2.31	—	4.24	—	488	Yellowfin	1.49	—	2.73	—
29	Bigeye	—	2.83	—	5.20	490	do	2.57	1.27	4.71	2.33
41	do	1.86	—	3.41	—	491	do	1.38	1.56	2.53	2.86
42	do	2.09	—	3.83	—	492	do	3.09	2.28	5.67	4.18
43	Yellowfin	2.17	3.61	3.98	6.62	493	do	—	2.00	—	3.67
46	do	—	2.85	—	5.23	546	Bigeye	2.73	2.76	5.01	5.06
49	Bigeye	—	2.10	—	3.85	549	do	—	1.99	—	3.65
52	do	—	2.22	—	4.07	550	do	—	2.24	—	4.11
53	Yellowfin	2.40	2.68	4.40	4.92	551	do	2.15	—	3.94	—
54	do	3.07	2.76	5.63	5.06	552	do	1.52	—	2.79	—
55	Bigeye	2.09	2.37	3.83	4.35	554	do	—	2.14	—	3.92
56	Yellowfin	—	2.06	—	3.78	557	do	—	1.72	—	3.15
58	Bigeye	1.91	2.34	3.50	4.29	558	do	2.59	3.11	4.75	5.70
59	Yellowfin	3.67	—	6.73	—	559	do	2.88	—	5.28	—
68	do	—	2.25	—	4.13	560	do	1.57	2.98	2.88	5.47
70	Bigeye	1.72	—	3.15	—	561	do	2.37	2.02	4.35	3.70
74	do	—	3.08	—	5.65	566	do	1.83	—	3.36	—
74	do	2.69	1.97	4.93	3.61	567	Yellowfin	2.78	4.12	5.10	7.56
78	do	—	4.08	—	7.48	569	Bigeye	—	1.05	—	1.93
6	Yellowfin	2.40	2.13	4.40	3.91						
72	do	2.86	1.93	5.25	3.54	Mean		2.31	2.27	4.23	4.16
72	do	—	1.55	—	2.84	Standard deviation		0.595	0.671	1.11	1.23

d/m/g wet tissue due to K^{40} was 4.23 for light and 4.16 for dark muscle. The standard deviations were 1.1 and 1.23, respectively. In a comparison of the mean potassium content of light and dark muscle, the *t*-test statistic was computed to be 0.117, indicating that for the sample tested there was no significant difference.

In summary, the mean potassium content of the tuna muscle examined was found to be 2.3 milligrams per gram of wet tissue, and the mean expected radioactivity from the naturally occurring potassium isotope K^{40} was calculated to be 4.2 disintegrations per minute per gram of wet tissue. The levels of potassium in light and dark muscle samples were not significantly different.

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REVIEWS

TUDIES ON SOCIAL GROUPINGS IN FISHES. *By C. M. Breder, Jr. (Bulletin of the American Museum of Natural History, Vol. 117, Art. 6). American Museum of Natural History, New York. 1959. pp. 393-482, 28 figs., 11 plates, 20 tables. $1.50.*

This paper is an extremely valuable and stimulating contribution to the study of the social behavior of fish. It is the latest and most comprehensive in a series of papers on fish groupings by Breder and represents his most recent thinking on the problems of why fish group themselves as they do. The arguments presented are based on a broad survey of the literature and on his own data collected over many years of studying marine and fresh-water fish, in their natural surroundings and in aquaria. A major section is devoted to a theoretical analysis of the causation of grouping behavior, based on some of the concepts of cybernetics. The paper is consistently well documented with pertinent literature references and contains many interesting examples, with some striking photographs.

Breder believes that all fish can be placed in one of the following descriptive categories: solitary, aggregating, schooling, or podding. Since these terms are used repeatedly through the paper and because there is some confusion in the literature over the differences between them, it is worth briefly listing Breder's definitions.

The *solitary* fish "... shows zero or less attraction for and towards others of its kind."

Aggregating fish "... are attracted to their kind, *per se*, independently of the accidental circumstances that might have brought them together in the first place ... They display no particular polarity as a group, nor is the group capable of any specific directional movement. These types of fishes are ordinarily orientated without reference to the orientation of other individuals."

Schooling species "... are attracted to their kind to a degree of unanimity of behaviour that impels them to swim in substantially similar paths, pack themselves more closely than is possible if not all orientated in one principal direction, and perform as a troupe of like-acting individuals in which independence of action is reduced to near the vanishing point. This is to say that the group is polarized and capable of forward movement as a unit."

Podding fish "... do not leave swimming clearance, and as a consequence they come into contact."

In a section titled *Special Forms of Social Groupings*, a number of unusual types of fish groups are described. One of the most interesting of these is the "pod", a name used by Florida fishermen to describe tightly packed bunches of *Mugil*. As described above, Breder uses it to include all of those fish groupings in which there is physical contact between individuals. The description and photographs of pods in this paper are among the first published accounts of this extraordinary phenomenon, one which is rarely if ever seen by most biologists.

In another part of the paper, the influences of some environmental variables on fish groupings are discussed. Among the many experiments described, several points are brought out which should be kept constantly in mind by anyone studying the behavior of captive fish. For example, young *Mugil cephalus* in the sea usually swim in loosely grouped aggregations, with only moderate uniformity of orientation among the individuals. When the same fish are captured and placed in an aquarium, they form a tight and persistent "fright school" with all members closely grouped, uniformly oriented and with the group moving as a unit. Anyone observing these fish only in an aquarium would wrongly conclude that *Mugil* of this size are typical and persistent schoolers.

Another valuable warning to the incautious laboratory worker is pointed out in an experiment with young *Jenkinsia*. Groups of fish from the same stock were held under different conditions of light and darkness and were then tested in a half-light, half-dark aquarium. The darker the surroundings in the previous holding area, the greater the percentage of fish staying in the dark half of the test tank. Thus, fish of the same species, size, and age did not show similar reactions to light and dark, but varied their reactions according to the conditions in the area where they had been held earlier.

In the same section, however, some of the new experiments described are based on very few fish. Others do not seem closely related to the central theme of the paper. For example, much information is given on the reactions of fish to various light intensities, but the link between these reactions and the grouping behavior of the fish is not always clear. There are also a number of slips or misprints, particularly in the graph and table legends.

Breder's main theoretical ideas on fish groupings are presented in a section titled *Structural Nature of Fish Groups*. Here the thesis is developed that the four types of social grouping shown by fish are not simply fortuitous formations, but that their number and form can be explained on mechanical grounds. Using the concepts and language of cybernetics, together with a formula he devised earlier to describe fish schools in purely quantitative terms, Breder suggests that fish are part of a system which has four stable points, represented by these four types of groupings. Between these points, there is instability, so that although the same fish may change from schooling to aggregating behavior, for example, they do so quickly and most of the time they either school or aggregate. The conclusion is reached that fish are part of a purely mechanical system which imposes or forces on them certain behavioral features, such as schooling or not schooling. The fish must cope with this system or die.

Breder insists that his analysis, with the detached viewpoint of the cyberneticist, is objective and pre-

cise and, therefore, has more chance of success in the long-term study of the significance of fish grouping behavior than have the more traditional biological methods used by ecologists and evolutionists. He suggests that "... without invoking any biological notions ..." he can go further in the analysis of the fundamental aspects of fish social behavior than can those workers who concentrate on such things as the survival value of schooling. Here he would seem to be overstating his case. It must be admitted that there are many casual and subjective interpretations of the functions of fish schools in the literature, but not all biologists interested in this problem have been subjective to the point of impotency. Most modern behaviorists are careful to confine their analyses within the limits of well-established biological principles. It is hard to believe that the social behavior of fish can be adequately analyzed solely on the basis of physical and mechanical principles, without involving some "biological notions".

This possible overemphasis on mechanical explanations does not, however, detract from the freshness and originality of the paper. Breder's concepts are based on long and extensive experience with the problems of fish sociology, and with such a solid background his novel method of analysis is sure to attract interest. Also, in spite of his obvious liking for objective mathematical analysis, Breder does not ignore biological principles altogether. His paper ends with the speculation that natural selection may have been the vital factor that allowed schooling behavior to evolve from more primitive forms of fish social organization.

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THE PHYSIOLOGY OF FISHES. *Ed. by Margaret E. Brown. Volume I, Metabolism; Volume 2, Behavior. Academic Press Inc., New York. 1957. v. 1, 447 pp., figs., tables, $12.00; v. 2, 526 pp., figs., tables, $14.00.*

This work represents an effort to bring together the large and very widely scattered body of information dealing with fish physiology. In all, the two volumes consist of 24 review articles, each by a specialist in the particular field treated.

Volume 1 is devoted largely to reviews of various organ systems and their functions. The most extensive chapter deals with respiration of both aquatic and air-breathing fishes. This chapter, together with that on the alimentary canal and digestion, comprises nearly one-third of the volume. Other articles are devoted to excretion and osmoregulation, skin and scales, endocrine organs, gonads and reproduction, and the cardiovascular system. Discussions of early development and hatching, experimental studies on growth, and the biochemical composition of fish are the respective subjects of the last three chapters.

The second volume is dominated by thorough treatments of the nervous system, sense organs, and behavior. The latter subject is dealt with in three parts: conditioned responses, ethological analysis of fish behavior, and reproductive and parental behavior. Three short chapters are given to specialized organs of fishes: the swimbladder, electric organs, and luminous organs. The volume is completed with sections on pigments, color changes, water-quality requirements and effects of toxic substances, and physiological genetics.

This ambitious task has been approached in a fairly careful manner. The various sections have been well integrated, as evidenced by the minimal amount of repetition. Furthermore, a good representation of appropriate references is provided in most cases. Particularly well handled in regard to general organization and clear exposition of presently unanswered problems are the chapters on digestion, endocrinology, the nervous system, and behavior. The discussions of water-quality requirements, growth studies, and biochemical composition should be particularly interesting to the experimental worker. This is also true of the section on physiological genetics which points up the importance of heredity as a factor to be controlled during experimentation by the use of inbred stocks.

As the editor points out in her preface, the subtitle of each volume is "used in a very broad sense". This comment is even more applicable to the title. The large amount of space devoted to anatomy, histology, and behavior suggests that physiology is practically synonymous with zoology. The extra-physiological material might be considered more as an unexpected blessing had other areas not been underplayed. However, two subjects which should have rated chapter headings are practically ignored—muscle physiology and intermediary metabolism. The latter important field is mentioned only secondarily in regard to endocrine functions and development of the egg and embryo. As a result, the significance of the chapter dealing with the biochemical composition of fish is left largely to the imagination of the reader. Muscle physiology is not discussed at all. If little work has been carried out in these fields (a condition which is especially true in the case of intermediary metabolism), the correspondingly large void in our information should be clearly outlined in a book which purports to indicate "gaps in knowledge and possible fruitful lines for further research".

The many excellent presentations which have been incorporated into this work make it an essential reference for those who have a special interest in functional studies of fishes. The two volumes represent the most complete accumulation of information of this kind. Furthermore, because of the considerable quantity of general information on fish zoology which has been included in *The Physiology of Fishes*, it also warrants the attention of the general fish or fishery biologist.

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FISHING AMONG THE INDIANS OF NORTHWESTERN CALIFORNIA. *By A. L. Kroeber and S. A. Barrett (Anthropological Records, Vol. 21, No. 1). University of California Press, Berkeley, Calif. 1960. 210 pp., 49 figs., 32 plates, 74 maps. $4.50.*

Fisheries workers with an interest in anthropology, ndians, and primitive fishing methods will find this comprehensive and useful volume. The many kinds f weirs, traps, nets, spears, and other fishing gear sed by the several Indian tribes of this region are escribed and illustrated, and information presented n their use and construction. Also discussed are shing customs, ownership of aboriginal fishing ghts, and processing and cooking of fish by Indians. here is an extensive bibliography, a glossary of rms, and an index.

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RINCIPLES OF FISHERIES DEVELOPMENT. *By C. J. Bottemanne. North-Holland Publishing Company, Amsterdam, Netherlands. 1959. xiv, 677 pp., 3 figs. $12.00.*

This volume analyzes the multitude of factors inuencing the structure of fisheries and establishes a attern of principles to serve as a basis for fishery evelopment policy. From comparative material, conomic and fishery literature, and personal exerience, the author presents an amazing insight into he properties of fisheries development. "Actual sea sheries" are the primary subject with the notation hat "onshore" or coastal fisheries, though highly roductive, offer few technical problems. It appears, owever, that the basic governing principles would sually apply to the coastal fisheries as well.

Initial sections deal with fish populations, methods f harvesting, and use of the resource, including a iscussion of eumetric fishing which, though fine in heory, cannot at present be applied in practice. he usual entrepreneur does not care whether fishng is eumetric or not, so long as he realizes a rofit, and the smart entrepreneur may make a andsome profit when it is dis-eumetric. Most of the iscussion concerning manageable variables in eumetric fishing, gear selectivity, and fishing intensity, directed toward the economic effects of changes s a means of control, *e.g.*, increased fishing effort enerally results in a lower catch-per-unit of effort hich eventually restricts the number of participants hat can fish profitably. Greater detail on the biogical effects of the common means of fishing ntensity regulation, such as the gear limitations nd catch quotas in the Pacific halibut fishery, ould have enhanced the analysis.

Features of dynamic fisheries are expounded and mplemented by examples of development drawn om past and existing fisheries. Reflecting the uthor's experience as adviser to a Holland trawler mpany, emphasis is placed on expansion of the orth Atlantic trawl fisheries although fisheries of her areas are included. The course of the European orth Atlantic fishery since the Middle Ages is folwed from its initial hook-and-line exploitation hrough phases characterized by improvement of ansportation and preserving methods, introduction steam power, development of the purse seine nd beam trawl, invention of otter boards for awling, and several more. These culminate with day's highly technical fishery employing vessels such as the British super trawler *Fairtry* on which the catch is mechanically filleted and deep-frozen at sea.

Complementary industries are introduced but without great detail. Although stating that the economic value of a fishery cannot be considered as merely the price paid the fisherman for his catch (as is common practice in most cases at present), the many industries associated with and arising from fishing are only mentioned. A method of estimating the economic value of the subsidiary industries stimulated by the "powerful income-generator", fishing, would have been appropriate in this discussion. The inherent and acquired structural problems of the fishing industry are revealed as the final section of Part III. Of special interest are the occasional comparisons between fishing and similar production industries.

Principles and problems of economic fishery development presented in detail, comprise the remainder of the treatise. Knowledge obtained while Head of the Institute for the Development of Sea-fisheries in the Netherlands East Indies, is utilized to great avail in depicting the course of fishery development. It is beyond the realm of this reviewer to attempt a critical evaluation of the many economic principles presented. Worthy of special note is the wealth of technical and background information found in notes following each chapter which forms an excellent reference source on many subjects.

Although most useful to the fishery administrator and the economist, the explanation of economic principles governing fishery development is of value to any biologist in better understanding the complexity of a fishery.

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AN INTRODUCTION TO THE BEHAVIOUR OF INVERTEBRATES. *By J. D. Carthy. George Allen and Unwin Ltd., London. 1958. 380 pp., 148 figs., 4 plates, 15 tables. 45s.*

"While preparing this book, it has become obvious that greater attention has been paid to the behaviour and sensory physiology of insects than to the rest of the invertebrates. An attempt has therefore been made to strike a balance and as far as possible to draw conclusions which may be applicable throughout the invertebrate subkingdom — though the very diversity of those animals militates against this. The mass of work still waiting to be done on invertebrates other than insects stands accentuated once again."

This opening paragraph in the preface stipulates two important objectives: 1) to achieve a balance between insects and the remainder of the invertebrates in the presentation and, 2) to formulate from the wealth of data presented, principles fundamental to the development of a unifying theory of invertebrate behavior. We may justifiably weigh the content of the book against these two points.

In the first case a tally of the forms listed in the species index (which in itself is a commendable

feature of the book) shows that of the slightly over 430 species referred to, 48 percent are concerned with insects and the remainder are scattered over 12 other major groups, with Coelenterata, Mollusca, and Crustacea claiming greatest attention. The present reviewer suggests that, although the great volume of work on insects contributes a preponderance of the available knowledge on invertebrate behavior, there is sufficient material on the other groups to provide a better balance than is attained here. There are sources of information in the publications of the fishery research organizations of the various nations which would have been of considerable help to the author in this respect.

To accumulate and organize the great array of facts presented in this small volume, and to present the very interesting and useful speculations in connection with them, must have been a very difficult task. In spite of all this the author failed to a large extent to gain the second objective. This is due partly to the imbalance referred to above, and partly to the tendency towards an anecdotal treatment of many isolated descriptions of behavior. The idea to "draw conclusions which may be applicable throughout the invertebrate subkingdom" is identifiable in the organization as itemized in the chapter headings. These headings are: Introductory; The Sense Organs; The Light Senses; The Perception of the Frequency and Plane of Vibration of Light Waves; The Perception of Form and Movement; Reactions to Heat; The Position Senses; The Perception of Vibration; The Tactile Senses; The Chemical Senses; The Contact Chemical Sense; Humidity Sensitivity; Whole Patterns of Behavior.

This reviewer respectfully suggests that a limited chapter-by-chapter discussion of the comparative morphology (such as is available) of invertebrate nervous systems and the known biochemistry and physical chemistry of receptors, along with the purely behavioristic material, would have aided the author in finding the general applicability that he so greatly desired. This approach would have provided greater perspective and scope for the recapitulation in the final chapter.

From the point of view of the fishery biologist, some important omissions are the failure to discuss bioluminescence in the chapter on light senses, and the absence of reference to the deep scattering layer in the discussion of plankton. The statement that plankton organisms migrate to the surface with the rising sun (page 215) is not in full agreement with generally accepted ideas.

All of the above notwithstanding, this is a useful book because it brings together much material on the behavior of invertebrates. There are 593 references distributed as follows: 1882-1900, 3 percent; 1901-1910, 3 percent; 1911-1920, 9 percent; 1921-1930, 19 percent; 1931-1940, 24 percent; 1941-1950, 15 percent; and 1951-1958, 27 percent. It would provide helpful collateral reading in both zoology and ecology courses, and a useful guide to the literature for graduate students and some professional workers.

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DANGEROUS MARINE ANIMALS. *By Bruce W. Halstead. Cornell Maritime Press, Cambridge, Maryland. 1959, 146 pp. 86 figs. $4.00.*

This little book is in part a semipopular version of a projected comprehensive treatise on toxic marine organisms. As such it will doubtless have much wider circulation than its parent work.

There is first a brief and interesting review of past information and misinformation going back to the Greeks and Romans. The following text is divided into three major sections: marine animals that bite, marine animals that sting; and marine animals that are poisonous to eat. The division, good in principle, is somewhat curious in practice. For instance, the bites of cephalopods, polychaetes, and snakes are listed under "stings", while the giant clam is considered a "biter". Moray eels are included as biters and also for no clear reason as stingers, since the author discounts any venomous apparatus. The general plan of each section lists harmful species or higher taxa, then gives methods for identification and a description of the particular harmful or toxic mechanism. Last is a paragraph or two on medical aspects and treatment, and practical hints on prevention. In discussing the medical aspects and treatment the author, a physician, is at his clearest and most authoritative.

Unfortunately, most of the treatments, except for surgical attention to bites from large fishes, are palliative at best. The basic plan seems to be removal of poisonous substances where possible, followed by nursing and rest. However, most of the accidents can be prevented, and the rules for prevention are sound and plentifully larded with common sense.

Illustrations of dangerous animals are abundant, well chosen, and remarkably well reproduced for offset printing. The overall effect of the illustrations is unfortunately marred since many are taken from other sources, and even the figures prepared especially for this volume vary from pencil sketches through ink drawings to airbrush paintings and photographs. Sometimes various techniques are combined in the same figure, with less than artistic results.

Nonetheless, this book should prove desirable for the marine fishery biologist's library and a good field handbook. Skindivers, collectors, and medical men, especially those who operate in tropical or semitropical seas, will find it most useful.

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RECENT PUBLICATIONS

CRUSTACEANA, INTERNATIONAL JOURNAL OF CRUSTACEAN RESEARCH. *Volume 1, Part 1, January 1960. E. J. Brill, Leiden. Gld. 36.*

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Yearbook of Fishery Statistics, Volume ix, 1958, Production and Fishing Craft. *1959. XXIX pp., 399 pp. $4.00.*

AO. General Fisheries Council for the Mediterranean.

Proceedings and Technical Papers, No. 5. *1959. 535 pp., figs., tables, maps.*

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An Ecological Study of the Recent Ostracods of the Gulf Coast of Flordia. *Florida State University, Tallahassee, Florida. 1958. 214 pp. Microfilm (University Microfilms, Ann Arbor, Michigan). $2.90.*

Nicol, J. A. Colin

The Biology of Marine Animals. *Interscience Publishers, Inc., New York. 1960. 707 pp., figs., tables. $14.00.*

Riley, Gordon A.

Oceanography of Long Island Sound. *(Bulletin of the Bingham Oceanographic Collection, Volume 17, Article 1, June 1959). Peabody Museum of Natural History, Yale University, New Haven, Conn. 1959. 153 pp. figs., tables.*

Scattergood, Leslie W., and S. N. Tibbo

The Herring Fishery of the Northwest Atlantic. *(Fisheries Research Board of Canada, Bulletin No. 121). The Queen's Printer, Ottawa. 1959. 42 pp., 25 figs., 3 tables. 75 cents.*

Waterman, Talbot H., ed.

Physiology of Crustacea. Volume 1, Metabolism and Growth. *Academic Press, New York. 1960. 670 pp. $22.00.*

William J. K. Harkness
1896-1960

Dr. William J. K. Harkness, who was a ader in North American fisheries circles r many years, passed away on July 5, 1960, ter a very brief illness. At the time of his ath he was chief of the Fish and Wildlife anch of the Ontario Department of Lands d Forests. He was also one of the Canadian mmissioners of the Great Lakes Fishery mmission. Throughout his career he had a ofound influence on the development of hery philosophy at both local and inter- tional levels. In addition to exchange pro- ssorships held at the University of Florida 940-1941) and Ohio State University 946), he was president of the American sheries Society (1951-1952), president of e Limnological Society of America (1940- 941), and president of the International ssociation of Game and Fish Commissioners 956-1957).

Dr. Harkness was born April 28, 1896, in oquois, Ontario, and received his early aining at St. Catherine's. After acquiring his achelor of arts and master of arts degrees Zoology at the University of Toronto in 22 and 1923, he was a lecturer at the niversity of Alberta. In 1941 he married argaret Blair Wylie. From 1924 through 946 he was associate professor of limnology at the University of Toronto. During this period he was director of the Ontario Fisheries Research Laboratory and established the first permanent fishery research station in Ontario at Algonquin Park. In 1946 he received his doctor of science degree at Ohio State University and was appointed chief of the Ontario Division of Fish and Wildlife. As director he did much to implement the principles developed during his many years as a research scholar and scientist.

The work of Dr. Harkness in the fields of limnology and fisheries was outstanding, but perhaps his greatest contributions were in the areas of application of basic knowledge to practical problems. His colleagues will remember him not only for the scientific insight and understanding to which his prolific writings testify, but for his wisdom in the approach to administrative and professional problems during a period of transition between empirical and scientific management of fishery resources. Recognition of the quality of his leadership is attested by the important offices in professional societies his coworkers conferred upon him and by the influence his research and administrative policies have had on his students and colleagues.